Chapter 18

Assessment of Age, Sex, Stature, Ancestry, and Identity of the individual

When osteological remains are recovered from forensic and archaeological situations, the osteologist is often called on to make more than just a determination of whether the remains are human. Human skeletal remains frequently reach the osteologist without any documentation about their individual sex, age, stature, or ancestry. The bulk of the literature on human osteology is composed of thousands of books and articles describing the development of methods to allow accurate and precise identification of individual traits in skeletal remains. This research continues today, even after more than a century of intensive study. All of this research and publication has been driven by the need for basic biological information about skeletal material from forensic and archaeological contexts. In archaeology, individual biological attributes of a skeleton become the fundamental components of work in the investigation of mortuary practices, paleopathology, and paleodemography. In forensic osteology, these individual biological attributes are important in narrowing the field of investigation to certain subsets of people and in **individuating** (establishing the individual identity of) the remains. This chapter is an introduction to the techniques that are used in determining the sex, age, stature, ancestry (biological/geographic/populational affinity or "race"), and individuation of human skeletal remains.

Our focus on the human skeletal elements in Chapters 4–13 was aimed at recognition, providing a guide to diagnostic aspects of human bones. Size and shape characteristics usually allow for the unambiguous sorting of human from nonhuman bone, even in very fragmentary material. Although the determination of sex from skeletal remains may appear to be an analogous binary decision, only a few skeletal characters allow the osteologist to make this choice. Furthermore, the other characteristics discussed in this chapter—individual age, stature, and ancestry—do not lend themselves to such easy and simple divisions as human/nonhuman or male/female. Rather, they grade continuously from pre-natal to elderly, from short to tall, and from one geographic group to another. For this reason, it is often best to consider determination of these characteristics as estimations (ideally, probabilistic estimations of facts) rather than as facts themselves.

18.1 Accuracy, Precision, and Reliability of Determinations

Accuracy is the degree to which a determination conforms to reality. Precision is the degree of refinement with which a determination is made. Aging a mandible as subadult might be accurate, for example, but it would still be imprecise. How accurately and precisely can an osteologist determine the sex, age, stature, and ancestry of human skeletal remains? There is no simple answer to the question. Any identification of a biological parameter such as sex, age, stature, or ancestry is, in effect, a probability statement. The likelihood that a given identification is accurate depends on a number of different factors that are worth general consideration before we turn to the analytical methods themselves.

- The accuracy and precision of determinations of sex, age, and ancestry depend on the broader age category to which the individual belongs. Younger individuals can, in general, be aged more precisely than older individuals. For example, tooth formation and eruption are well-documented, although somewhat variable, and the timing of epiphyseal formation and fusion is likewise well-established. As these growth processes taper off at maturity, there is little continuing skeletal change to monitor. Subsequent changes in the adult skeleton are often degenerative and task- or health-specific, and therefore not as well-correlated with age. Although precise skeletal aging becomes more difficult with adults, establishing the sex of an individual becomes easier. This is because many sexual characteristics of the skeleton become most pronounced only once an individual begins to sexually mature. Most of the criteria established for deducing ancestry are only useful in comparisons between adults. Krogman and İşcan (1986) provide a more detailed overview of these concerns in their text on forensic osteology.
- The accuracy and precision of determinations depend on available skeletal elements. Different elements have different developmental stages. Some criteria, such as dental eruption sequence, correspond more closely to chronological age than others, such as cranial suture closure. Some skeletal elements, such as the pubis, display sexually diagnostic characteristics, whereas others do not. Some elements, such as the femur, show high correlations with stature, whereas others do not. Some bones of the cranium are useful in discriminating between modern human groups, and others are not.
- The accuracy and precision of determinations depend on sample composition. Accuracy of identification diminishes when the osteologist is forced to identify isolated individuals by means of age and sex standards derived from other populations. The most accurate and precise sexing and aging estimates are obtained when it is possible to arrange many skeletal specimens in a series (to **seriate**) and to compare within a single biological population. For estimating sex, age, or ancestry, it is always a great advantage to work with populations of skeletons rather than with isolated finds. This is sometimes the case in archaeological settings, but forensic settings rarely provide the opportunity to work with large unknown samples.
- The accuracy and precision of determinations depend on the analytical methods used. Different methods yield determinations of sex and age that have different reliabilities. For example, sexing a pubis with the Phenice technique (Section 18.4.4) is highly reliable, whereas using the width of the sciatic notch is far less reliable.
- The accuracy and precision of determinations depend on the suitability of the analytical methods to the unknown individual or sample. Most standards used for sexing and aging skeletal remains have been established on the basis of modern European and American skeletal series. These standards have not been shown to apply equally to human populations in other parts of the world or from prehistoric contexts (see Mensforth and Lovejoy, 1985; Ubelaker, 1987; King et al., 1998), and some studies have suggested that interpopulational differences limit their utility (Schmitt, 2004). Not only is there variation within single populations in the rate of skeletal maturation, but there is also significant variation

between populations (Lampl and Johnson, 1996). This factor is significant due to the limited number of populations on which the currently used methods have been based (Section 18.2).

- The accuracy and precision of determinations depend on research context. The degree of accuracy needed in a particular analysis depends on the questions being asked and the problems being investigated. If the problem involves merely sorting subadult mandibles from adult mandibles, accuracy should be 100%. However, if the investigation necessitates separation of 35-year-old from 36-year-old mandibles, no known method will be accurate.

18.2 From Known to Unknown: Using Standard Series

To determine the biological attributes of sex, age, stature, or ancestry for skeletal remains, the osteologist must proceed by comparing — directly or indirectly — the unknown skeletal elements to a standard series of population- and age-appropriate skeletal individuals with reliably known ages, sexes, statures, and ancestries. Where do such series exist? Not in many places — certainly not in archaeological cemeteries that lack written records. Radiographic studies of modern human development have proven important in establishing aging standards for use by osteologists. Unfortunately, many features of bones are not easily visible by plane (*i.e.,* two-dimensional) radiography. Some interesting work is being done using three-dimensional volume-rendered CT scans as comparative series (*e.g.,* Ramsthaler et al., 2010), but the technique is not widely accepted and there are currently no 3-D data sets of complete series of known individuals.

What osteologists have done when attempting to solve for the unknown biological qualities of skeletal material is to make intensive use of any of several major skeletal collections in which there are more-or-less adequate records of sex, age, stature, and ancestry (see Table 18.1 for a detailed listing of these collections). Standards and methods developed from these collections all suffer some limitations. In North American collections, racial categories are, for the most part, "black" and "white," which are legal and social terms based on local custom rather than biological ancestry. Admixture is unaccounted for. Those collections that originate from dissection rooms are often biased towards those of below-average socioeconomic status, and males significantly outnumber females. In most cases, the ages of death recorded in the collection records are not self- or family-reported, but are only estimates made by the coroner, often rounded to the nearest five years in adults.

To summarize, the accuracy and precision of an osteologist's attributions of sex, age, or stature to a skeleton for which these variables are unknown always depend on standards derived from a series of skeletons originally accompanied by independent records of these same biological attributes. There are significant problems involved with assessing the biological attributes of archaeologically derived skeletal material using these and other collections of modern human bones. The most important among these problems is that few series contain nonmodern individuals and fewer still contain people who lived under aboriginal, non-Western subsistence conditions. The effects of different lifestyles on individuals that make up skeletal series can be dramatic. For example, the rate and degree of tooth wear are higher in aboriginal populations, as is the amount of muscular stress and osteological reaction to that stress. It is critical to keep the limitations of skeletal collections in mind when using them (or the data derived from them) to assist in making determinations of age, sex, stature, or ancestry.

18.3 Estimation of Age

Individual age determination in skeletal remains involves estimating the individual's age at the time of death (as opposed to the amount of time that has elapsed since death). Ubelaker (1989: 63) succinctly encapsulates the procedures and problems inherent in aging skeletal remains:

Collection, Location	Individuals	Dates of death	Sex bias?	Age bias?	Ancestry	Available for research?
Hamann-Todd coll., Case Western Reserve Univ. Cleveland, OH	3713	1912–1938	80% male (2979♂:700♀) *(34 unknown sex)*	most 20–80 (range: 0–105)	61% "white" 38% "black"	Yes
Korean War dead, U.S. Army Quartermaster Corps	450	1950–1953	primarily male	most 17–25 (range: 17–50)	primarily "white"	No: reburied 1956–1958
Terry collection, Washington, DC	1728	1920–1965	59% male (1018♂/713♀)	most ≥ 45 (range: 14–102)	45% "white" 54% "black"	Yes
Huntington collection, Washington, DC	4054	1892–1920	75% male		about 70% "white"	Yes
Chief Medical-Examiner's office, Los Angeles, CA	1225	1977–1979	60% male (739♂/486♀)	range: 14–99		
W. Montague Cobb coll., Washington, DC	634	1932–1969	70% male (684♂/287♀)	most > 25 (only 13 ≤ 25)	84% "black" 19% "white"	Yes
NMNH Fetal collection, Washington, DC	320	1904–1917	54% male (152♂/129♀)	Fetal–neonate only	43% "white" 54% "black"	Yes
Maxwell collection Albuquerque, NM	257 and growing	1975–present		range: 0–80+		Yes
Bass collection, Knoxville, TN	669	1981–present	71% male (491♂/170♀)	80% adult (536/669)		Yes
Univ. of Iowa/Stanford coll. Iowa City, IA	1100	1910s–1920s				Yes
St. Thomas' cemetery, Ontario, Canada	579	1821–1874			European-Amer.	No: reburied
J.C.B. Grant collection, Toronto, Ontario, Canada	202	1928–early 1950s	87% male (176♂/26♀)	73% are over 40 years old	European-Amer.	Yes
Christ Church, Spitalfields, London, UK	968	1729–1859		81% adult (782/968)	European	Yes
St. Bride's Church, London, UK	244	1761–1851		94% ≥ 18 (range: 0–91)	European	Yes
Universiteit Leiden, Netherlands					European	
Museu Bocage collection, Lisbon, Portugal	1692 and growing	1880–1975	"sexes equally represented"	"adults and juveniles"	European	Yes
Coimbra cemetery coll., Portugal	570	1904–1938	63% male (357♂, 213♀)		European	Yes
Dart collection, Johannesburg, SA	2605	1920s–present	71% male (1840♂, 756♀)	94% ≥ 20 (range: 1–100)	71% "SA African" 18% "white"	Yes
Cape Town Univ., South Africa	ca. 200	1980–1999		most ≥ 50	African	Yes
Pretoria bone collection, South Africa	290 skeletons 704 skulls 541 postcrania	1943–present		range: 0–100	African	Yes

Table 18.1 **Documented skeletal collections.** Some of the major collections of identified individuals from which standards for aging, sexing, stature, and ancestry have been, and continue to be, formulated.

Documentation	References
Individuals from low socioeconomic status, collected from area hospitals. Only about 16% of the individuals in this collection have sufficiently reliable ages at death to be used in skeletal aging studies.	Thompson (1982) CMNH (n.d.)
A large set of skeletons of American military personnel killed in the Korean War. The set consisted primarily of male individuals with a limited age distribution. Data have seen wide use in estimating age for bony remains.	McKern and Stewart (1957) Coleman (2008)
From Washington University's Anatomy Department, now housed at the Smithsonian Institution's National Museum of Natural History.	Hunt and Albanese (2005)
European immigrants, NYC residents. Curated at the Smithsonian Institution's National Museum of Natural History.	NMNH (n.d.)
Pubic bones gathered from autopsied individuals in Los Angeles County.	Brooks and Suchey (1990)
Remains of individuals used as cadavers in anatomy classes at Howard University. African-Americans from the Washington, DC, area.	Watkins (in press)
Individuals are from spontaneous abortions and still births. Most are from Washington, DC, and Baltimore, MD, but collection includes some from Germany.	Huxley (2005)
	Komar and Grivas (2008)
Bodies are donated and used for decomposition research before being skeletonized.	Wilson *et al.* (2007)
Individuals from diverse ethnic groups who died in the San Francisco area, originally curated at Stanford University.	Schermer *et al.* (2000)
Historic cemetery site in Belleville, Ontario, Canada. Approximately 37% of the total of 1564 interments were recovered, 80 of which are positively identified.	Saunders *et al.* (1993a)
Individuals originally received by the Anatomy Department from local hospitals and welfare institutions. Now curated at the Dept. of Anthropology.	
Historic cemetery site in England.	Cox (1996, 1998) Molleson and Cox (1993)
19th Century lead-coffin burials recovered from the crypt of St. Brides Church in England. The crypt was discovered after the church was destroyed in 1940.	Ivanhoe (1982) Scheuer and Bowman (1995)
	MacLaughlin and Bruce (1986)
Individuals recovered from three cemeteries in Lisbon. 699 individuals have specific biographic data associated, including sex, age at death, cause of death, etc.	Cardoso (2005, 2006)
Historic cemetery site in Lisbon.	MacLaughlin (1990b) Cunha (1995)
Most of the collection derives from unclaimed bodies in regional South African hospitals. Identified to ethnic group.	Saunders and DeVito (1991) Dayal *et al.* (2009)
	Robinson and Bidmos (2009)
The collection is derived from the nearly 6500 cadavers accepted for use in teaching medical anatomy. Only individuals with known sex, age, and ancestry become part of the research collection.	L'Abbé *et al.* (2005) Robinson and Bidmos (2009)

Estimation of age-at-death involves observing morphological features in the skeletal remains, comparing the information with changes recorded for recent populations of known age, and then estimating any sources of variability likely to exist between the prehistoric and the recent population furnishing the documented data. This third step is seldom recognized or discussed in osteological studies, but it represents a significant element.

However, many of the attributes that are used to determine biological age do not seem to be environmentally plastic. The degree to which age standards derived from modern osteological collections may be applied to prehistoric populations is a matter of continuing debate (Hoppa, 2000), but available studies indicate that individual variation often swamps populational differences.

Over the course of a lifetime, elements of the skeleton undergo sequential chronological change. In infancy these changes primarily involve the appearance of various skeletal elements. During childhood and adolescence, bones and teeth continue to appear, and epiphyses form and fuse. Even after age 20, bones continue to fuse, metamorphose, and degenerate. This progression forms the foundation for studies of skeletal aging. However, it is important to note that even normal development of the infant is discontinuous and saltatory (Lampl et al., 1992), and that there is substantial variation among different individuals in the rate and timing of developmental changes. Pathology can also play a role (Sherwood et al., 2000).

Whereas sex identification in skeletal remains is dichotomous, determination of the age-at-death of an individual is more complex because it involves arbitrarily dividing the continuum of growth. Individuals of the same chronological age can show different degrees of development. This is true for skeletal anatomy as well as for behavior. Thus, even when osteological standards based on known samples are perfect, there is always a degree of imprecision in aging skeletal remains. What is the magnitude of this imprecision?

As noted earlier, whether dealing with cranial bones, teeth, or postcranial elements, an already-established "system" is used for osteological aging; criteria for aging are identified based on a population whose individuals have known ages. It is possible, for example, to use radiographs of people in living populations to establish that human permanent molars erupt at about 6, 12, and 18 years of age. This control series can then be used to age each individual in an unknown skeletal series, under the assumption that dental eruption followed the same periodicity in both groups.

One drawback in such an approach to an unknown skeletal series is that age assignments are made on an individual basis, without reference to other individuals in the unknown series. Such assignments place individuals into an **age range** (for instance, 12–18 years) or an **age class** (for instance, "young adult"—see Figure 18.1). This aging is not as precise as assigning an absolute age, for example, of 15 years. In other words, the more coarsely you divide a continuum, the more imprecise the aging. As Lovejoy and colleagues (1997) note, there are two major sources of error in any estimate of age-at-death. These are the inherent variation within the biological process of aging itself, and the investigator's skill in estimating the biological age of the unknown specimen. Furthermore, as Falys and Lewis (in press) point out, there are alarming discrepancies in the use of even broad age classes, such as "adult."

An approach that should always be taken with a large sample of unknown individuals to help overcome these imprecisions is **seriation**. Prior to estimating each unknown individual's age, all of the individuals represented by the skeletal element under analysis in the unknown series are arranged in a sequence of increasing age. This approach has many benefits (Lovejoy et al, 1985): seriation may be done quickly, with little fatigue; there is no observer error due to time-shift effects (*e.g.,* having to stop in the middle of the analysis because the work day ends); there is constant monitoring of results, with ability to correct observer errors; and there is no loss of accuracy as a result of pooling individuals into age categories. Once the sample under analysis is seriated, at least the individuals have been aged *relative to each other*.

Seven age classes commonly used to segregate human osteological remains are as follows: **fetus** (before birth), **infant** (0–3 years), **child** (3–12 years), **adolescent** (12–20 years), **young adult** (20–35 years), **middle adult** (35–50 years), and **old adult** (50+ years) (Buikstra and Ubelaker, 1994; see Figure 18.1). Scheuer and Black's volumes (2000, 2004) represent excellent resources for work involving the aging of immature human skeletal remains.

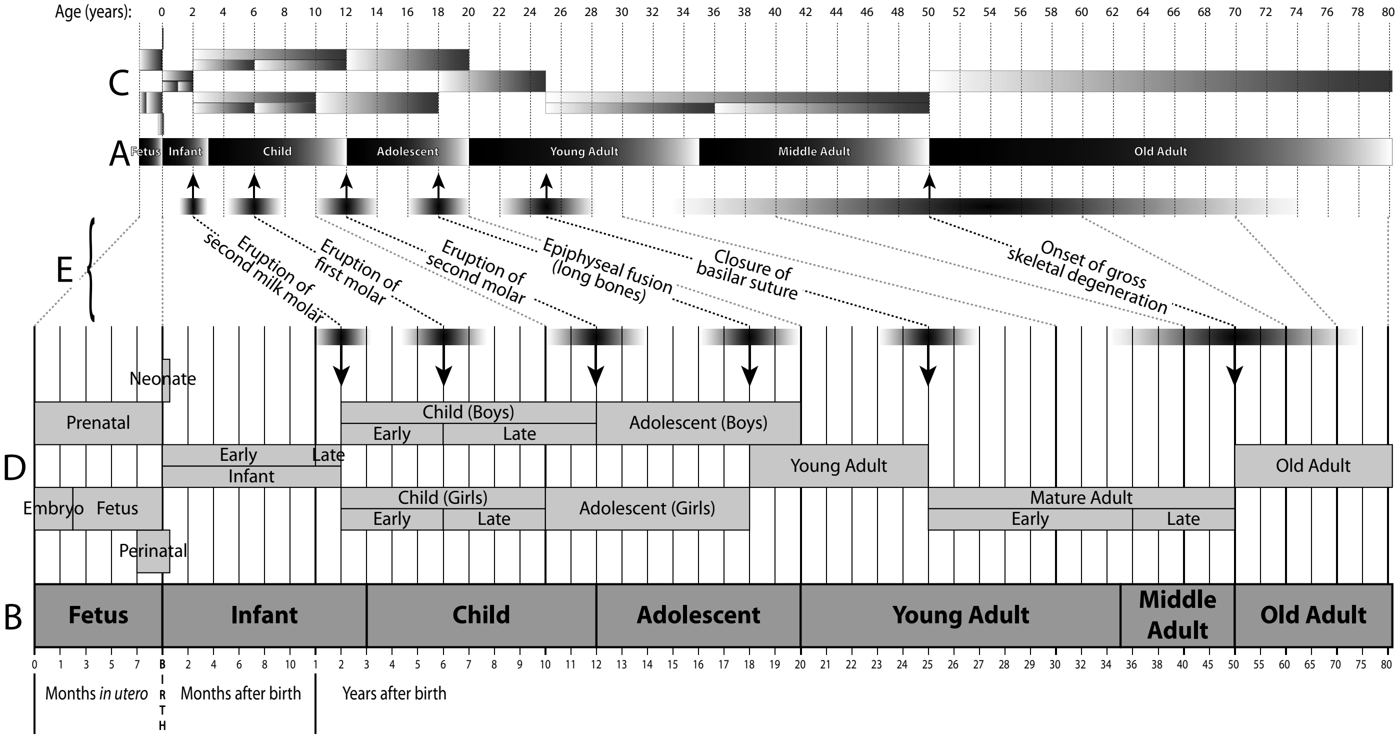


Figure 18.1 **Age classes.** The seven age classes proposed in Buikstra and Ubelaker's (1994) Standards volume (A, B), and some alternative age classification terms (C, D) that are more closely tied to developmental milestones (E). **A**) The seven proposed age classes presented on a linear scale. Age-related changes do not occur at a uniform rate throughout life, but rather occur rapidly in the first third of life, then become increasingly slow through the remainder of an individual's lifetime. **B**) The same seven proposed age classes presented on a nonlinear scale. The classification terms shown at C and D are likewise identical, presented on the two scales. The nonlinear scale gives more emphasis to periods of life that witness more age-related changes, and less emphasis to periods of life with fewer age-related changes. This nonlinear scale will be used in similar diagrams (Figures 18.3, 18.5, 18.8, 18.9, 18.10, 18.14, 18.16, 18.17, 18.18, and 18.19) throughout the rest of this chapter. Because the meanings of terms such as "Young Adult" and "Child" can vary between age classification systems, it is important to specify which system you are using.

18.3.1 Estimating Subadult Age from Teeth

Eruption and wear of the teeth have been used extensively in aging the human skeleton. Tooth development is more closely associated with chronological age than is the development of most other skeletal parts, and it seems to be under tighter genetic control. Because of the regular formation and eruption times for teeth and because these elements are the remains found most commonly in forensic, archaeological, and paleontological contexts, dental development is the most widely used technique for aging subadult remains. Smith (1991) provides a review of the various techniques available. It is important to note that "regular" does not mean "constant." For example, some infants erupt their teeth earlier in their lives, and different individuals erupt their teeth in different orders (Smith and Garn, 1987). It has been shown that some African-Americans and European-Americans differ in both rate and sexual dimorphism of tooth mineralization (Harris and McKee, 1990).

Tooth formation begins in the embryo a mere 14–16 weeks after conception (Hillson, 1996). There are four distinct periods of emergence of the human dentition. First, most deciduous teeth emerge during the second year of life. The two permanent incisors and the first permanent molar usually emerge between 6 and 8 years. Most permanent canines, premolars, and second molars emerge between 10 and 12 years. Finally, the third molar emerges around 18 years. Of course, there is idiosyncratic variation in all tooth development and eruption.

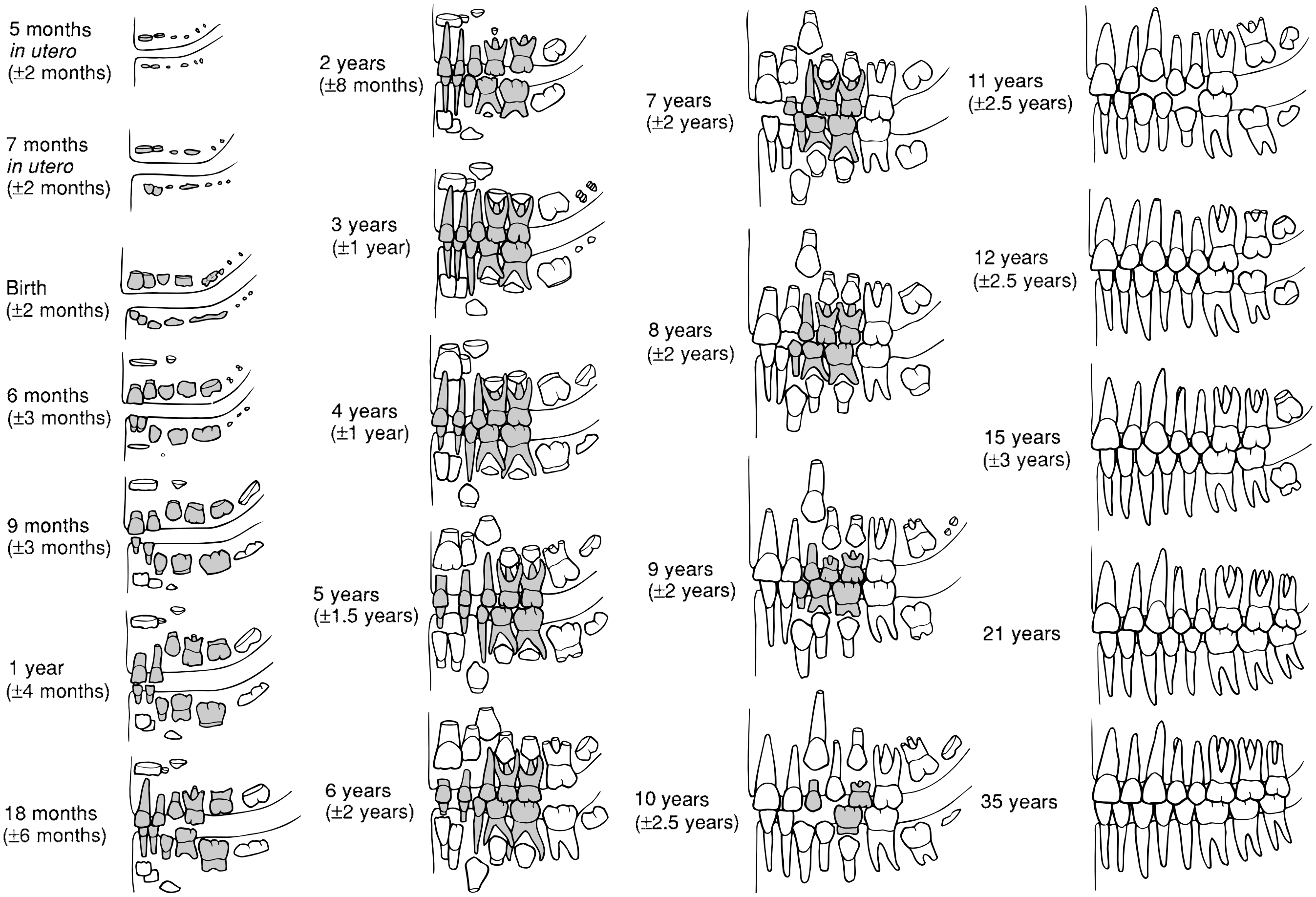


Figure 18.2 **Dental development in Native Americans.** Adapted from Ubelaker (1999); note that data on the deciduous teeth come from non-Native Americans.

Age may be determined from developing teeth in several ways. One means is by comparing the unknown individual with a chart or atlas showing the mean stage of development of the entire dentition (Figures 18.2 and 18.3). Another is through comparison of the stages of formation with each individual tooth (Table 18.2). Liversidge (1994) discusses the pros and cons of these methods and recommends the atlas approach for both accuracy and ease of use. Hillson (1996) provides an excellent review of all methods of aging the skeleton through use of dental development. The third molar is the most variable tooth in formation and eruption. Mincer et al. (1993) provide data on the formation of this tooth and its use in age estimation.

Ubelaker (2008) provides a graphic summary of data on dental development in Native Americans, which we reproduce in Figure 18.2. Note the possible ranges associated with each stage in the diagram. Figure 18.3 shows the source of these errors. Sex-based variation in development and eruption of teeth is most apparent at the canine position, and this tooth should be afforded less attention when aging erupting dentitions. When assessing the age of a subadult individual based on teeth, note all aspects of development, including the completeness of all crowns and roots (**formation**) and the place of each tooth relative to the alveolar margin (**eruption**). When using published standards, be sure to discriminate between emergence through the alveolar margin (bone) or through the gum (soft tissue). Also note that dental development is sensitive to sex and population differences (İşcan, 1988). For more details on dental development and eruption, see Trodden (1982) and Smith (1991).

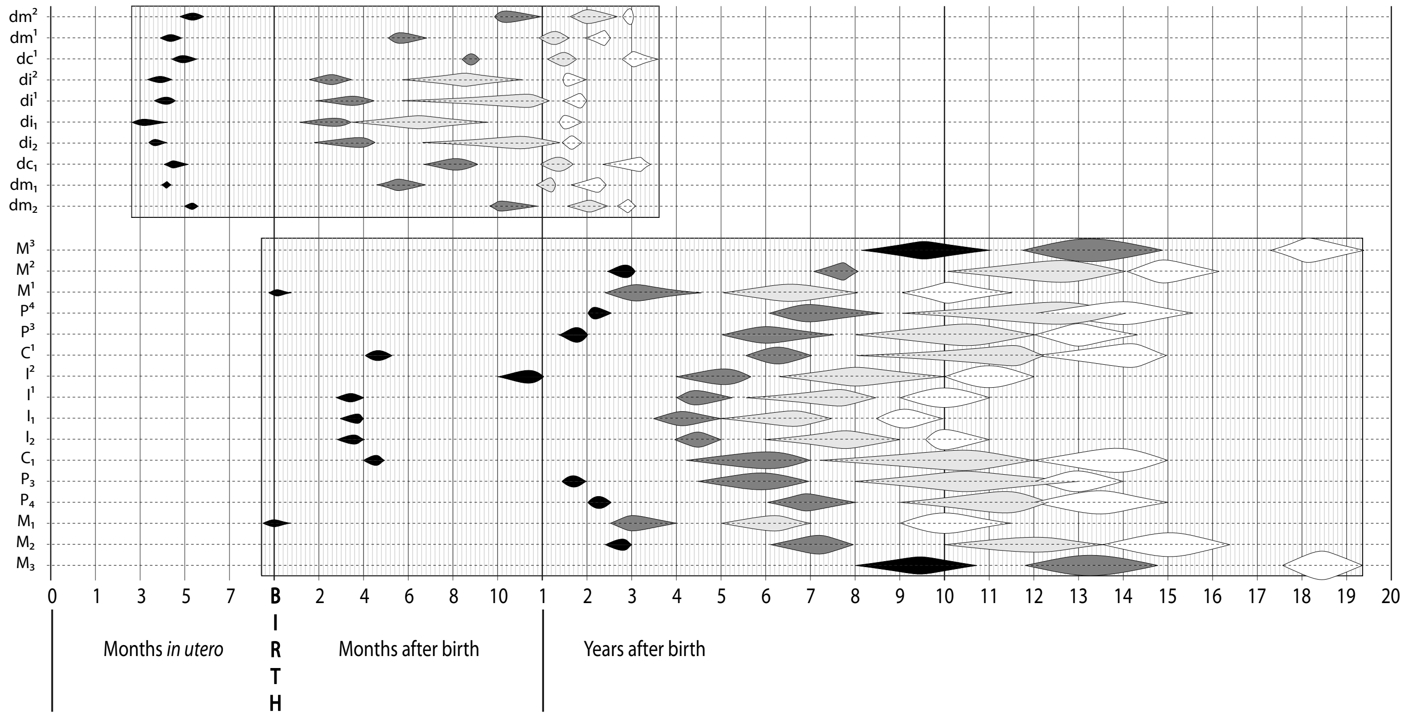


Figure 18.3 **Variation in the timing of dental development.** Range values are ±1 SD for the third molars. *Key:* black: crown mineralization begins; dark gray: crown completion; light gray: eruption; white: root completion. For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Based on data from Gustafson and Koch (1974), with third molar data from Anderson *et al.* (1976).

18.3.2 Estimating Adult Age from Teeth

Once a permanent tooth erupts, it begins to wear. Rate and patterns of wear are governed by tooth developmental sequences, tooth morphology, tooth size, internal crown structure, tooth angulation, nondietary tooth use, the biomechanics of chewing, and diet (McKee and Molnar, 1988; Walker et al., 1991). If the rate of wear within a population is fairly homogeneous, it follows that the extent of wear is a function of age. This fact can be used in assigning dental ages to adult specimens. Where this has been tested on modern populations, correlations between known age and tooth wear have been shown to be good (Lovejoy et al., 1985; Richards and Miller, 1991). However, the osteologist should always be on the lookout for cases of accelerated wear due to pathology or use of the teeth as tools (Milner and Larsen, 1991).

The first step in assessing age by dental attrition is application of a seriation of all dentitions based on development and wear. Miles (1963) was the first to establish a scale of attrition based on development. The basics of the technique are as utilized in the following example: A first molar accumulates about 6 years of wear before the second molar of the same individual erupts (assuming eruption at 6 and 12 years, respectively). When a similar amount of wear (6 years' worth) is found on a third molar of another individual (a molar assumed to have erupted at age 18), the age of that individual can be estimated as $18+6=24$ years. Miles uses 6.0, 6.5, and 7.0 years between successive molar eruption. The technique underestimates individuals over 50 years of age (Miles, 2001). A variety of other techniques have been applied to the quantification of tooth wear (Molnar, 1971; Scott, 1979; Brothwell, 1989; Walker et al., 1991; Dreier, 1994; Mayhall and Kageyamu, 1997).

Lovejoy (1985) has concluded, for the prehistoric Libben skeletal population, a large human osteological series from the midwestern United States, that dental wear assessed by seriation pro-

Table 18.2 **Average age (in years) of a skeletal individual based on an assessment of dental development at each crown position**[a]

		di1	di2	dc	dm1	dm2	I1	I2	C	P3	P4	M1	M2	M3
A. MALES														
Ci	Cusp initiation	—	—	—	—	—	—	—	0.6	2.1	3.2	0.1	3.8	9.5
Cco	Cusp coalescence	—	—	—	—	—	—	—	1.0	2.6	3.9	0.4	4.3	10.0
Coc	Crown outline complete	—	—	—	—	—	—	—	1.7	3.3	4.5	0.8	4.9	10.6
Cr ½	Crown one half	—	—	—	—	—	—	—	2.5	4.1	5.0	1.3	5.4	11.3
Cr ¾	Crown three-fourths	—	—	—	—	—	—	—	3.4	4.9	5.8	1.9	6.1	11.8
Crc	Crown complete	0.15	0.2	0.7	0.4	0.7	—	—	4.4	5.6	6.6	2.5	6.8	12.4
Ri	Root initiated	—	—	—	—	—	—	—	5.2	6.4	7.3	3.2	7.6	13.2
Rcl	Root cleft present	—	—	—	—	—	—	—	—	—	—	4.1	8.7	14.1
R ¼	Root one-fourth	—	—	—	—	—	—	5.8	6.9	7.8	8.6	4.9	9.8	14.8
R ½	Root one-half	—	—	—	—	—	5.6	6.6	8.8	9.3	10.1	5.5	10.6	15.6
R ⅔	Root two-thirds	—	—	—	—	—	6.2	7.2	—	—	—	—	—	—
R ¾	Root three-fourths	—	—	—	—	—	6.7	7.7	9.9	10.2	11.2	6.1	11.4	16.4
Rc	Root complete	1.5	1.75	3.1	2.0	3.1	7.3	8.3	11.0	11.2	12.2	7.0	12.3	17.5
A ½	Root apex half closed	—	—	—	—	—	7.9	8.9	12.4	12.7	13.5	8.5	13.9	19.1

		di1	di2	dc	dm1	dm2	I1	I2	C	P3	P4	M1	M2	M3
B. FEMALES														
Ci	Cusp initiation	—	—	—	—	—	—	—	0.6	2.0	3.3	0.2	3.6	9.9
Cco	Cusp coalescence	—	—	—	—	—	—	—	1.0	2.5	3.9	0.5	4.0	10.4
Coc	Crown outline complete	—	—	—	—	—	—	—	1.6	3.2	4.5	0.9	4.5	11.0
Cr ½	Crown one half	—	—	—	—	—	—	—	2.5	4.0	5.1	1.3	5.1	11.5
Cr ¾	Crown three-fourths	—	—	—	—	—	—	—	3.5	4.7	5.8	1.8	5.8	12.0
Crc	Crown complete	0.15	0.2	0.7	0.3	0.7	—	—	4.3	5.4	6.5	2.4	6.6	12.6
Ri	Root initiated	—	—	—	—	—	—	—	5.0	6.1	7.2	3.1	7.3	13.2
Rcl	Root cleft present	—	—	—	—	—	—	—	—	—	—	4.0	8.4	14.1
R ¼	Root one-fourth	—	—	—	—	—	4.8	5.0	6.2	7.4	8.2	4.8	9.5	15.2
R ½	Root one-half	—	—	—	—	—	5.4	5.6	7.7	8.7	9.4	5.4	10.3	16.2
R ⅔	Root two-thirds	—	—	—	—	—	5.9	6.2	—	—	—	—	—	—
R ¾	Root three-fourths	—	—	—	—	—	6.4	7.0	8.6	9.6	10.3	5.8	11.0	16.9
Rc	Root complete	1.5	1.75	3.0	1.8	2.8	7.0	7.9	9.4	10.5	11.3	6.5	11.8	17.7
A ½	Root apex half closed	—	—	—	—	—	7.5	8.3	10.6	11.6	12.8	7.9	13.5	19.5

[a] The data are from Smith's (1991) compilation of published studies.

cedures is an important and reliable indicator of adult age-at-death. He found, on the populational level, that dental wear was very regular in form and rate. As Lovejoy notes, the assessment of a single individual in a forensic setting based on dental wear allows only a gross approximation of age, but if an entire biological population is seriated, tooth wear can yield precise results. In fact, Lovejoy and colleagues (1985a) concluded that dental wear is the best single indicator for determining the age of death in skeletal populations. They found dental wear as an age indicator to be accurate and consistently without bias. Figure 18.4 illustrates the wear standards used by these workers. Mays (2002) has also found dental wear to be a reliable indicator in a very different historical Dutch skeletal collection.

Hillson (2005) and Whittaker (2000) discuss methods useful in assessing individual age based on microscopic analysis of the permanent teeth. As teeth age, formation of secondary dentine reduces the coronal height of the pulp cavity. Drusini et al. (1997) used this to age radiographs of adult individuals to ±5 years on 78% of teeth assessed. Other studies have shown that apical translucency of tooth roots correlates with adult age, but applications of the technique have shown it to be less useful than other methods (Kvaal et al., 1994). In some forensic cases, a combination of gingival regression and root transparency may allow aging of adults over 40 and under 80 years of age with a mean error of estimation of ± 10 years (Lamendin et al., 1992). Soomer et

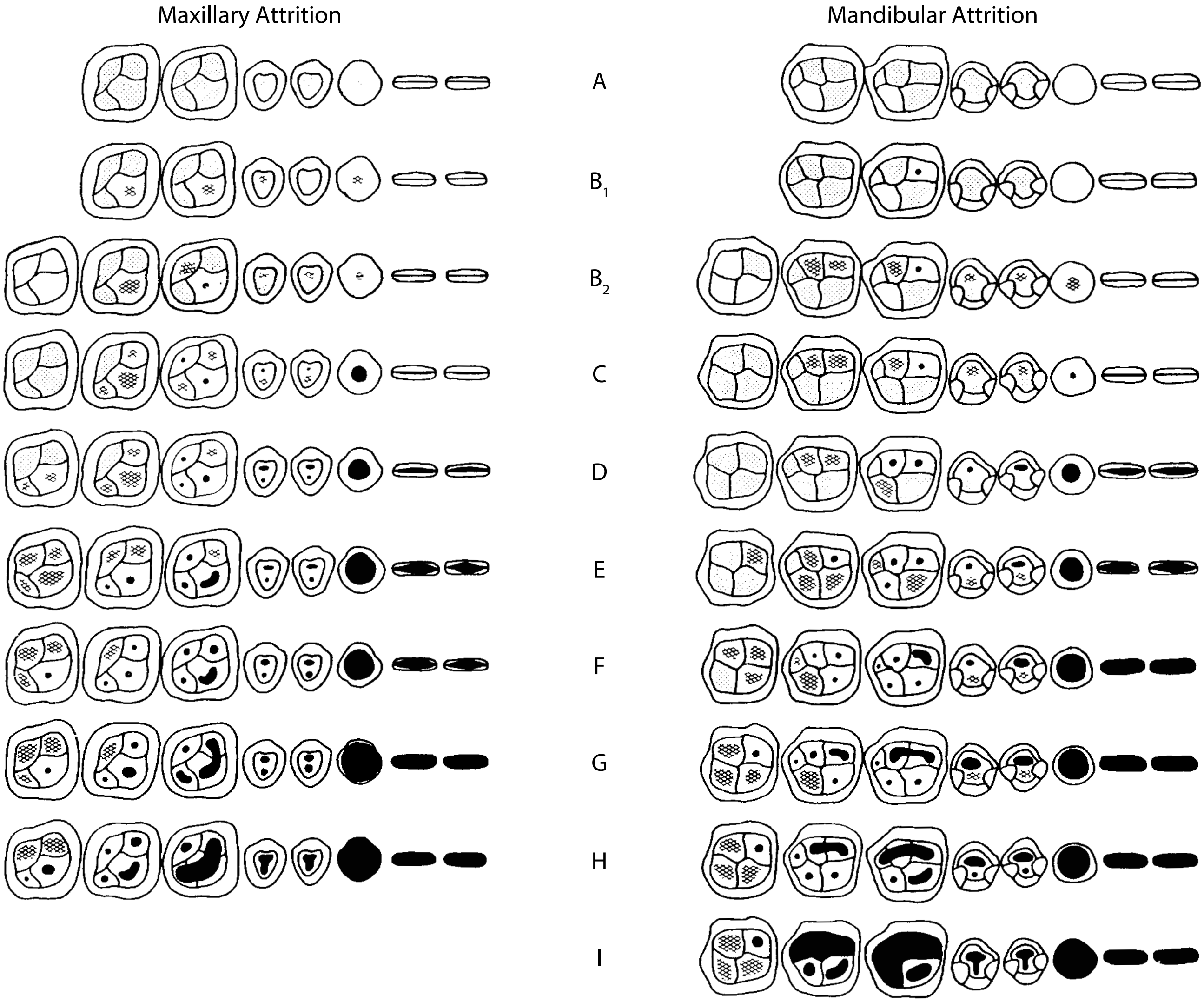


Figure 18.4 **Modal tooth-wear patterns of a prehistoric Native American population from Libben, Ohio.** Wear is divided into phases for right maxillary (*left*) and left mandibular (*right*) dentitions. Exposed dentine is shown in black. Age in years for the various phases are as follows: A, 12–18; B_1, 16–20; B_2, 16–20; C, 18–22; D, 20–24; E, 24–30; F, 30–35; G, 35–40; H (maxillary), 40–50; H (mandibular), 40–45; I, 45–55. See Lovejoy (1985) for a full description.

al. (2003) provide a comparative overview of various methods applied in forensic work. Amino acid racemization of dentin-derived collagen has become an effective estimator of age in forensic remains (Ohtani and Yamamoto, 1991, 1992, 2005). Griffen et al. (2009) apply this method to archaeological enamel and report that diagenesis of the enamel makes this a poor age indicator in archaeological remains.

18.3.3 Estimating Adult Age from Cranial Suture Closure

It has been appreciated since the 1500s that sutures between various cranial bones fuse progressively as the individual ages. In the early 1900s suture closure enjoyed widespread use in skeletal aging, but the false promise of one or two accurate indicators of adult skeletal age during the

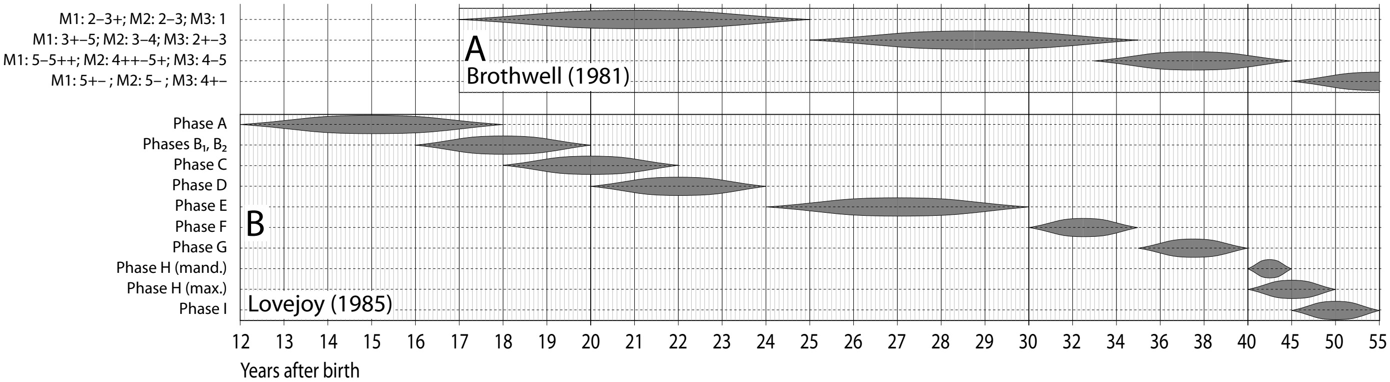


Figure 18.5 **Estimates of age that can be obtained through analysis of dental attrition.** **A**) Age estimates that can be obtained with the Brothwell system, based on a Neolithic to Medieval British sample; **B**) age estimates that can be obtained using the Lovejoy system. The gray spindles illustrate the published range. For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data for A are taken from stated ranges in Brothwell (1981), and data for B are derived from Lovejoy (1985).

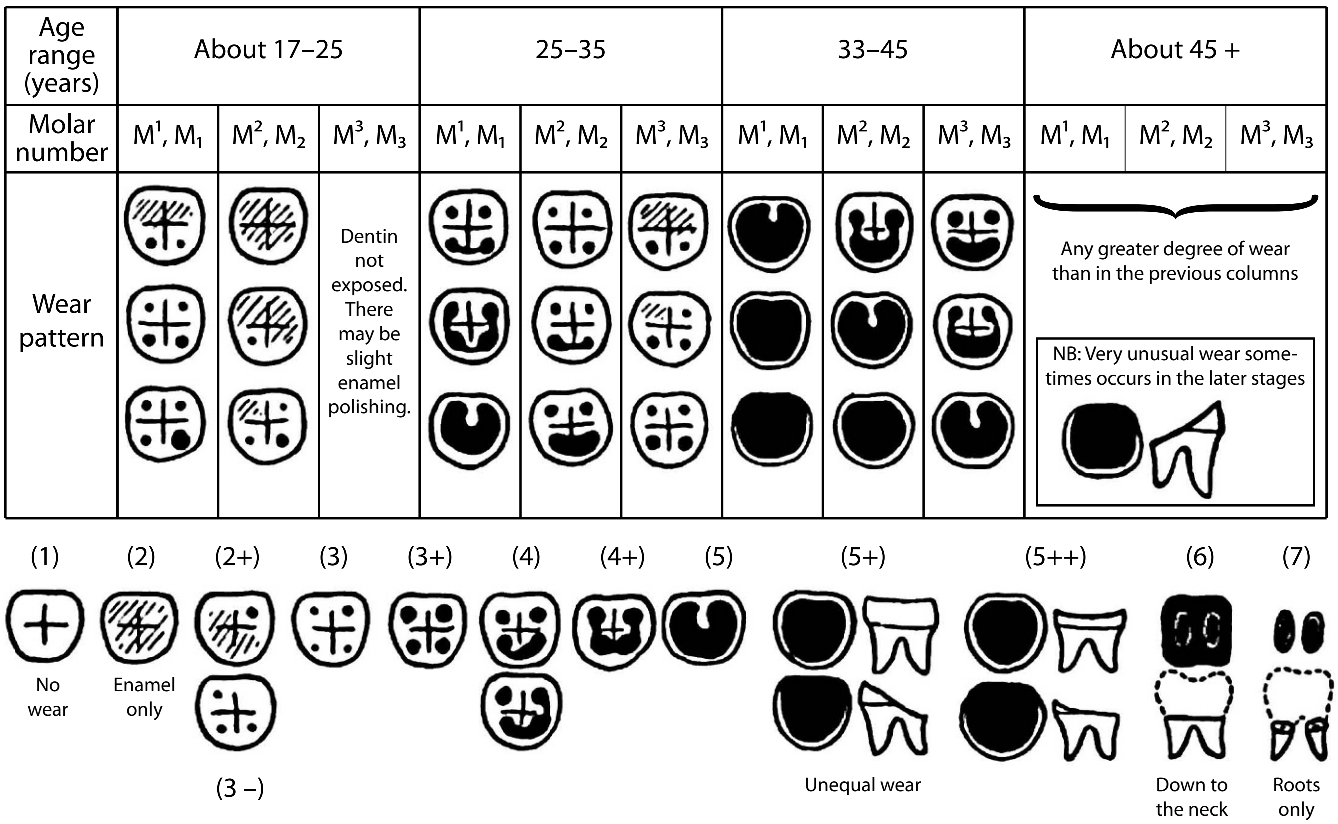


Figure 18.6 **Tooth-wear patterns derived from a sample of prehistoric to medieval English skeletons**. *Top*: typical patterns of wear characteristic of four broad age ranges. *Below*: numerical wear scores for molars. Exposed dentine is shown in black, and worn enamel is hatched. Adapted from Brothwell (1981).

1950s (such as metamorphosis of the pubic symphysis) led to disuse of the technique. Meindl and Lovejoy (1985), however, reinvigorated the study of cranial suture closure. They chose a series of 1-cm segments of ten sutures or suture sites and scored these on a scale of 0 (open) to 3 (complete obliteration). The results erased some of the prejudice against suture closure assessment as a means of skeletal aging in the adult and stimulated more research in this area. Galera et al. (1998) provide a comparative analysis of different cranial suture aging methods. One cranial feature, the sphenooccipital synchondrosis, is particularly useful in aging isolated crania because at least 95% of all individuals have fusion here between 20 and 25 years of age, with a central tendency at 23 years of age (Krogman and İşcan, 1986).

Other cranial sutures show more variation in age of closure. The Ley et al. (1994) work on the Spitalfields population from Britain indicates that there may be sexual and interpopulational differences in the rates of suture closure. This study developed yet another technique of scoring suture closure. The Buikstra and Ubelaker Standards volume (1994) recommends that 17 cranial suture segments each be given a numerical score. The score of 0, or **open**, is given when there is no evidence of any ectocranial closure. A score of 1 is given to suture sites with **minimal closure**. A score of 2 is given to sites with **significant closure**, and a score of 3 is given to a **completely obliterated** suture (complete fusion). Figure 18.7 shows the location of the 1-cm sutural sites.

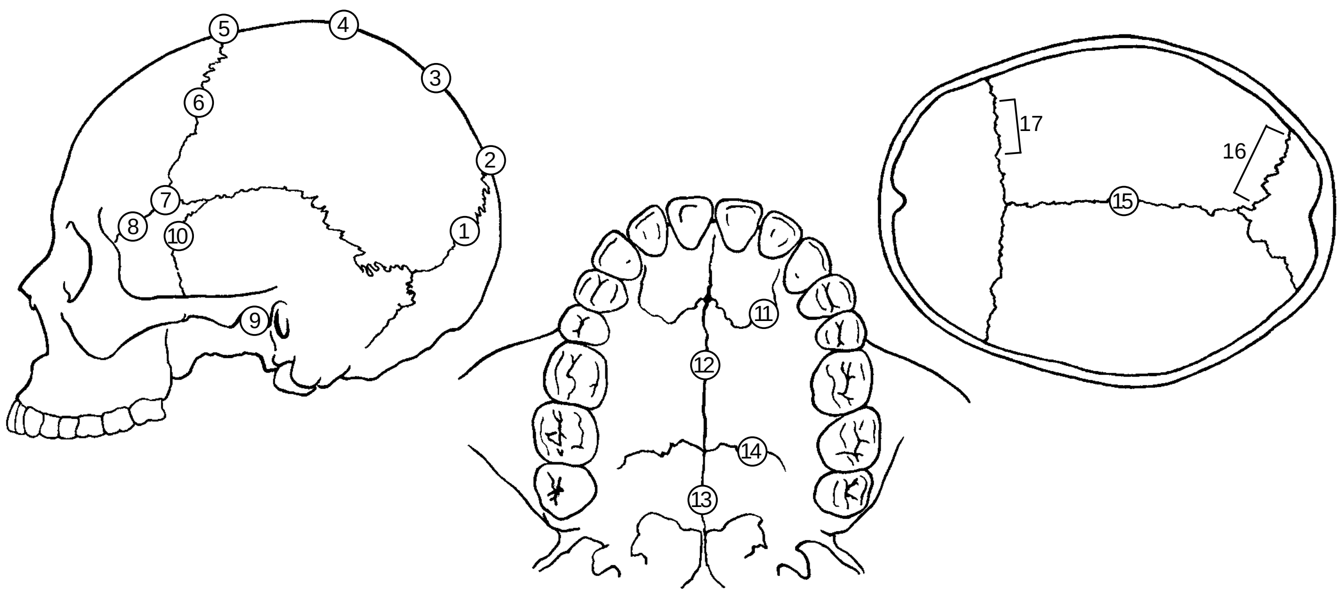
18.3.4 Estimating Subadult Age from Long Bone Length

In the absence of teeth and various epiphyses, subadult individual age may be estimated from long bone length. This procedure of subadult skeletal aging is not as exact as others and should always be done with reference to the same or a closely related skeletal collection. Seriate the growth series and compare the isolated long bone lengths to the series in order to derive ages. In the absence of such series, the data presented in Ubelaker (2008) and Scheuer and Black (2000) are useful for age assessment (Figure 18.9).

18.3.5 Estimating Subadult Age from Epiphyseal Closure

Fusion of a postcranial epiphysis is orderly, and an epiphysis fuses at a known age. However, these ages vary by individual, sex, and population. As Stevenson (1924) points out, the intensity of epiphyseal activity is greatest between ages 15 and 23. Fusion of the epiphysis is progressive and is usually scored as unfused (nonunion), united, or fully fused (complete union). The beginning of epiphyseal union for several elements overlaps the conclusion of tooth eruption, making these aging techniques complementary. Figure 18.11 illustrates the considerable idiosyncratic variation in the chronology of epiphyseal union for several human skeletal elements using data taken from male Korean War dead (McKern and Stewart, 1957). Much of the work on epiphyseal union has been done on long bones, but recent work on vertebrae show the utility of these elements, particularly in aging teenagers and young adults (Albert and Maples, 1995).

It should be noted that union begins earlier in females than in males and that different individuals of the same sex can show very different times of union. The last epiphysis to fuse is usually the medial clavicle, at about 21 years. Late-fusing bones such as the clavicle, however, show wide variation in age at fusion. For example, some medial clavicle epiphyses fuse before 21 years, whereas other individuals show persistent nonfusion at age 30 [for more references, consult Stevenson (1924); Mensforth and Lovejoy (1985); Webb and Suchey (1985); and Krogman and İşcan (1986)]. Growth ends once fusion of all epiphyses occurs, under 28 years of age for the great majority of cases. As a result, fewer age indicators remain for the postcranial skeleton of the adult individual.



Site		Description
1	Midlambdoid	Midpoint of left lambdoid suture
2	Lambda	Intersection of sagittal and lambdoid sutures
3	Obelion	At obelion
4	Anterior sagittal	One-third the distance from bregma to lambda
5	Bregma	At bregma
6	Midcoronal	Midpoint of left coronal suture
7	Pterion	Usually where the parietosphenoid suture meets the frontal
8	Sphenofrontal	Midpoint of left sphenofrontal suture
9	Inferior sphenotemporal	Intersection of left sphenotemporal suture and line between articular tubercles of the temporomandibular joint
10	Superior sphenotemporal	On left sphenotemporal suture 2 cm below junction with parietal
11	Incisive suture	Incisive suture separating maxilla and premaxilla
12	Anterior median palatine	Score entire length on paired maxillae between incisive foramen and palatine bone
13	Posterior median palatine	Score entire length
14	Transverse palatine	Score entire length
15	Sagittal (endocr.)	Entire sagittal suture endocranially
16	Left lambdoid (endocr.)	Score indicated portion
17	Left coronal (endocr.)	Score indicated portion

Meindl and Lovejoy (1985) "vault" sutural ages (add scores for sites 1–7).			Meindl and Lovejoy (1985) "lateral-anterior" sutural ages (add scores for sites 6–10).		
Composite Score	*Mean Age*	*Standard Deviation*	*Composite Score*	*Mean Age*	*Standard Deviation*
0	—	—	0	—	—
1–2	30.5	9.6	1	32.0	8.3
3–6	34.7	7.8	2	36.2	6.2
7–11	39.4	9.1	3–5	41.1	10.0
12–15	45.2	12.6	6	43.4	10.7
16–18	48.8	10.5	7–8	45.5	8.9
19–20	51.5	12.6	9–10	51.9	12.5
21	—	—	11–14	56.2	8.5
			15	—	—

Figure 18.7 **Cranial suture fusion sites, their scoring, and interpretation.** After P. Walker, in Buikstra and Ubelaker, (1994). A score of from 0 (unfused) to 3 (completely obliterated) is assigned to each site. Sites are 1-centimeter ectocranial segments of the sutures as shown. Endocranial segments are slightly larger. In the Meindl and Lovejoy (1985) system, scores are independently summed for vault (numbers 1–7) and lateral-anterior (numbers 5–10) sites. Other suture sites, such as the maxillary suture (Mann et al., 1991), have been used to segregate individuals into even broader age categories, but their use in forensic cases has been questioned (*e.g.,* Gruspier and Mullen, 1991).

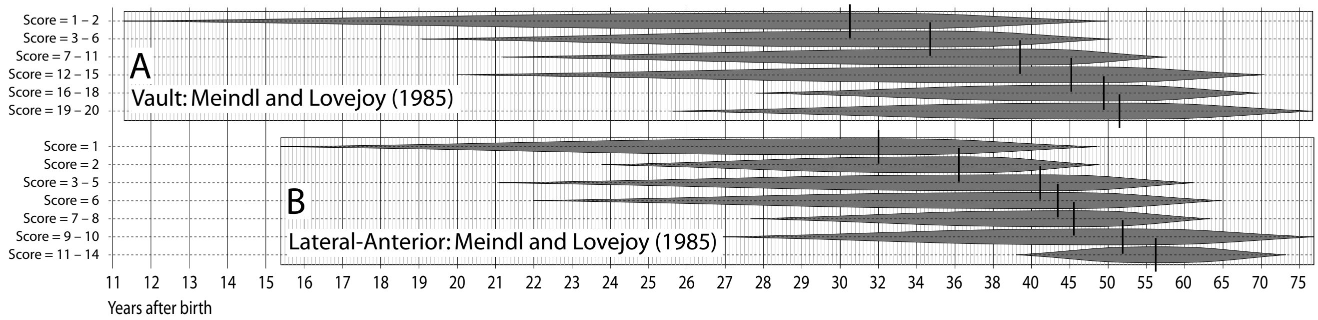


Figure 18.8 **Estimates of age that can be obtained through analysis of cranial suture fusion. A**) Composite fusion scores for vault sutures; **B**) composite fusion scores for lateral-anterior sutures. The short black vertical lines represent mean ages for each phase, and the gray spindles represent ±2 SD (≅95% range). For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data are derived from Meindl and Lovejoy (1985:63).

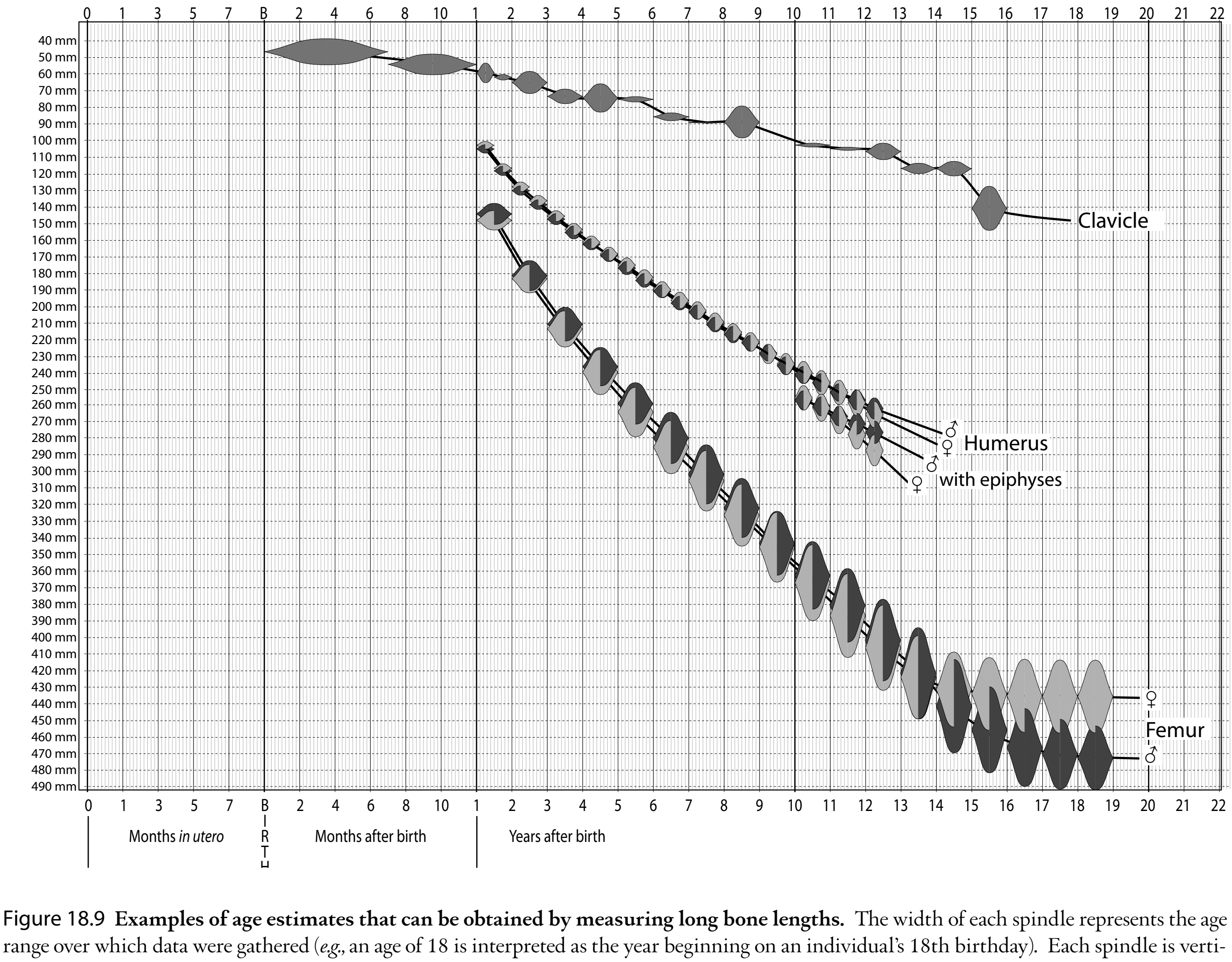


Figure 18.9 **Examples of age estimates that can be obtained by measuring long bone lengths.** The width of each spindle represents the age range over which data were gathered (*e.g.*, an age of 18 is interpreted as the year beginning on an individual's 18th birthday). Each spindle is vertically centered on the mean length for that age range, and the height of each spindle represents the ±1 SD range. *Key:* dark gray: males; light gray: females; medium gray: combined sexes. For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Clavicular data are based on Scheuer and Black (2000:252), humeral data are based on Scheuer and Black (2000:289, citing Maresh, 1970), and femoral data are based on Scheuer and Black (2000:395, citing Anderson et al., 1964).

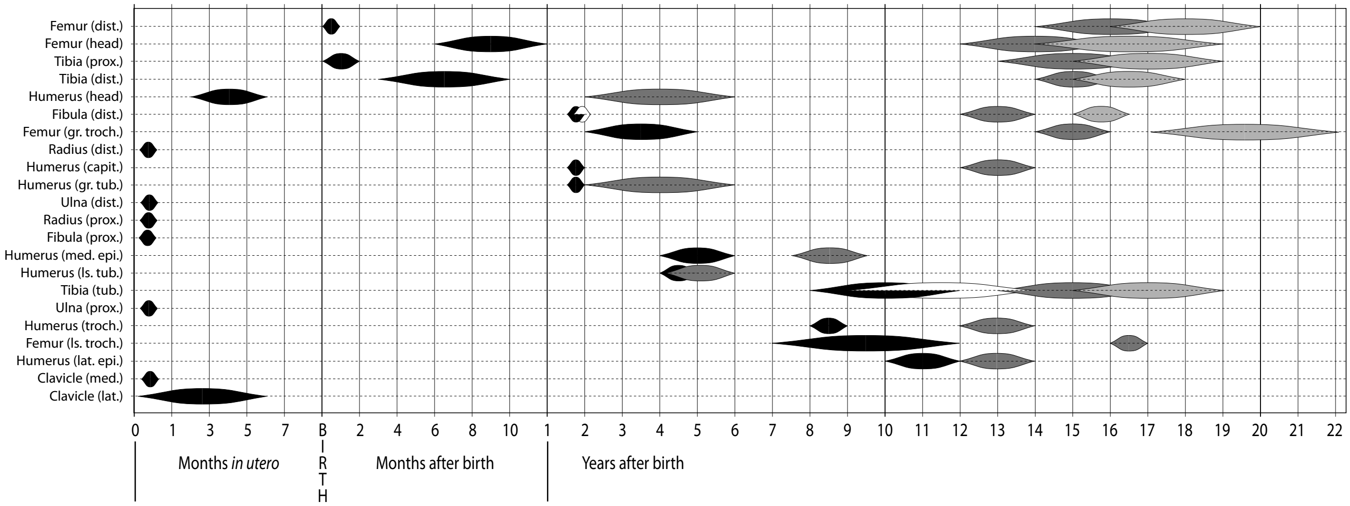


Figure 18.10 **Variation in the times of appearance and fusion of secondary ossification centers for the major long bones.** *Key:* black: appearance of secondary center of ossification (in both sexes or, if paired with a white marker, in females); white: appearance of secondary center of ossification in males; dark gray: fusion of the secondary center of ossification (in both sexes or, if paired with a light gray marker, in females); dark gray: fusion of the secondary center of ossification in males. For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data are derived from Scheuer and Black (2000).

18.3.6 Estimating Adult Age from the Pubic Symphyseal Surface

One of the most widely used indicators of age-at-death has been metamorphosis of the symphyseal surface of the pubis of the os coxae. Age-related changes on this surface continue after full adult stature has been achieved and other epiphyses of the limbs have fused. Pubic symphyses of other primates metamorphose more quickly than human ones and usually synostose with advancing age. In humans, however, changes of the symphyseal surfaces allow them to be used in generating osteologically determined age-at-death estimates. The young adult human pubic symphysis has a rugged surface traversed by horizontal ridges and intervening grooves. This surface loses relief with age and is bounded by a rim by age 35. Subsequent erosion and general deterioration of the surface are progressive changes after this age. Figure 18.12 illustrates these changes.

Age-related changes at the pubic symphysis have been recognized for many years, and the first formal system for using these changes to determine age was developed by Todd (1920), based on a series of 306 males of known age-at-death. Todd identified four basic parts to the pubic symphysis, a surface with an irregular oval shape: (a) the ventral border (rampart), (b) the dorsal border (rampart), (c) the superior extremity, and (d) the inferior extremity. Todd noted evidence of billowing, ridging, ossific nodules, and texture on each part of the symphyseal surface. Using these observations on his sample of known ages, Todd recognized ten phases of pubic symphysis age, ranging from 18/19 years to 50+ years, and noted that these phases were more reliable age indicators between 20 and 40 years than after 40 years. He perceived three major stages in symphysis metamorphosis. His phases I–III comprised the "postadolescent" stage, phases IV–VI were the buildup stage, and phases VII–X represented the degenerative stage. Figure 18.12 illustrates Todd's original standards; subsequent work on age-based changes in this anatomical region is based on this foundation.

Few tests of this method were made, although the method gained wide acceptance. Brooks (1955) found a tendency of the Todd system to overage, especially in the third and fourth decades. In 1957, McKern and Stewart used skeletal remains of 349 male Korean War dead in an effort to

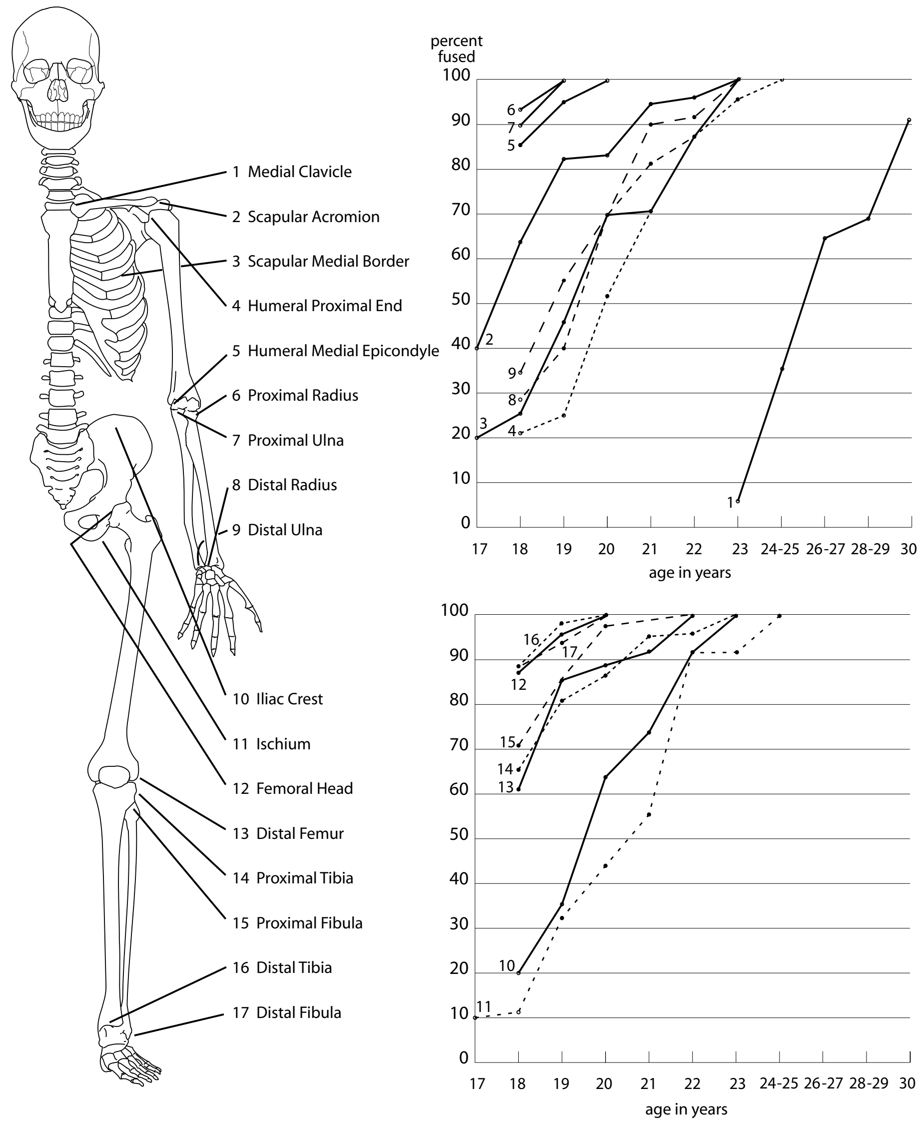


Figure 18.11 **Ages of fusion for various male skeletal elements.** Data on fusion from McKern and Stewart (1957). These standards, derived from U.S. military personnel who died in the Korean War, show considerable variation in fusion for any given element. For example, in the medial clavicle, McKern and Stewart (1957) found that of 10 individuals aged 17 years, none had fused epiphyses. For the clavicle, the epiphyseal cap begins to unite to the medial end of the clavicle as early as 18 years but can begin to unite at any time between 18 and 25 years. The earliest complete fusion came among some soldiers who died at 23 years, but the study showed that others lived to age 31 before fusion was complete. To use this table, choose a numbered epiphysis from above or below the waist and find its graph to the right of the skeleton. The graph shows what percentage of adult male individuals showed full fusion of each epiphysis at any given age.

refine the Todd method. Their approach was to divide the symphyseal surface longitudinally into two halves, or "components"—the "dorsal demiface" and the "ventral demiface." The third component of the symphysis was the "symphyseal rim." Five developmental stages were recognized for each of the three components. In using this system, the osteologist calculates a developmental stage for each component, adds these together, and derives an age of death for the specimen. This system, like that of Todd, was derived from an all-male sample of limited age range.

Gilbert and McKern (1973) used a sample of 103 females of known age to generate a component system for aging female specimens by the pubis. Because female pubic symphyses are subject to trauma during childbearing, there is a potential for premature changes in the bone surface, which could lead to overaging. In 1979, Suchey tested the Gilbert and McKern method for aging the female pubic symphysis by asking 23 professional osteologists to age pubic faces of unrevealed age. Results showed the system to be highly unreliable and prone to inaccurate estimates.

Meindl and colleagues (1985a) tested the accuracy of all these methods in a study of the Hamann-Todd collection. They found that the original Todd method was more reliable than the

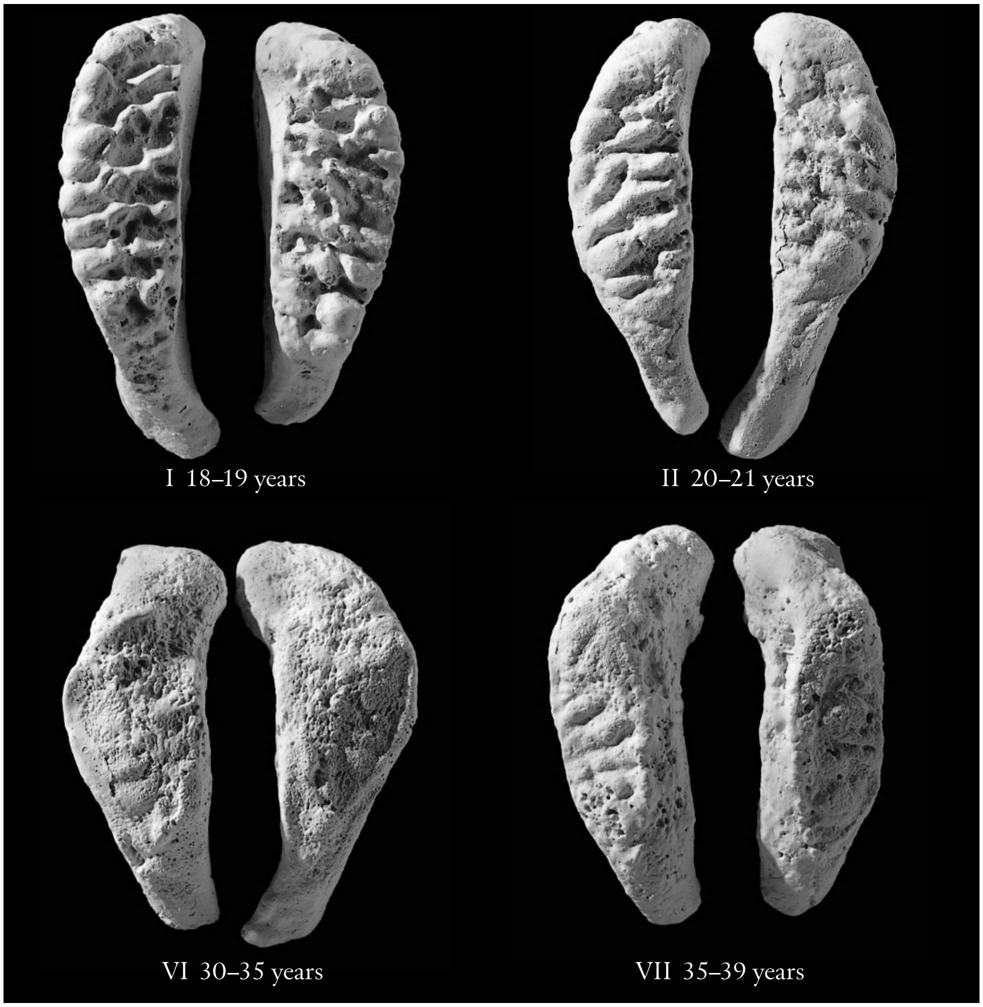
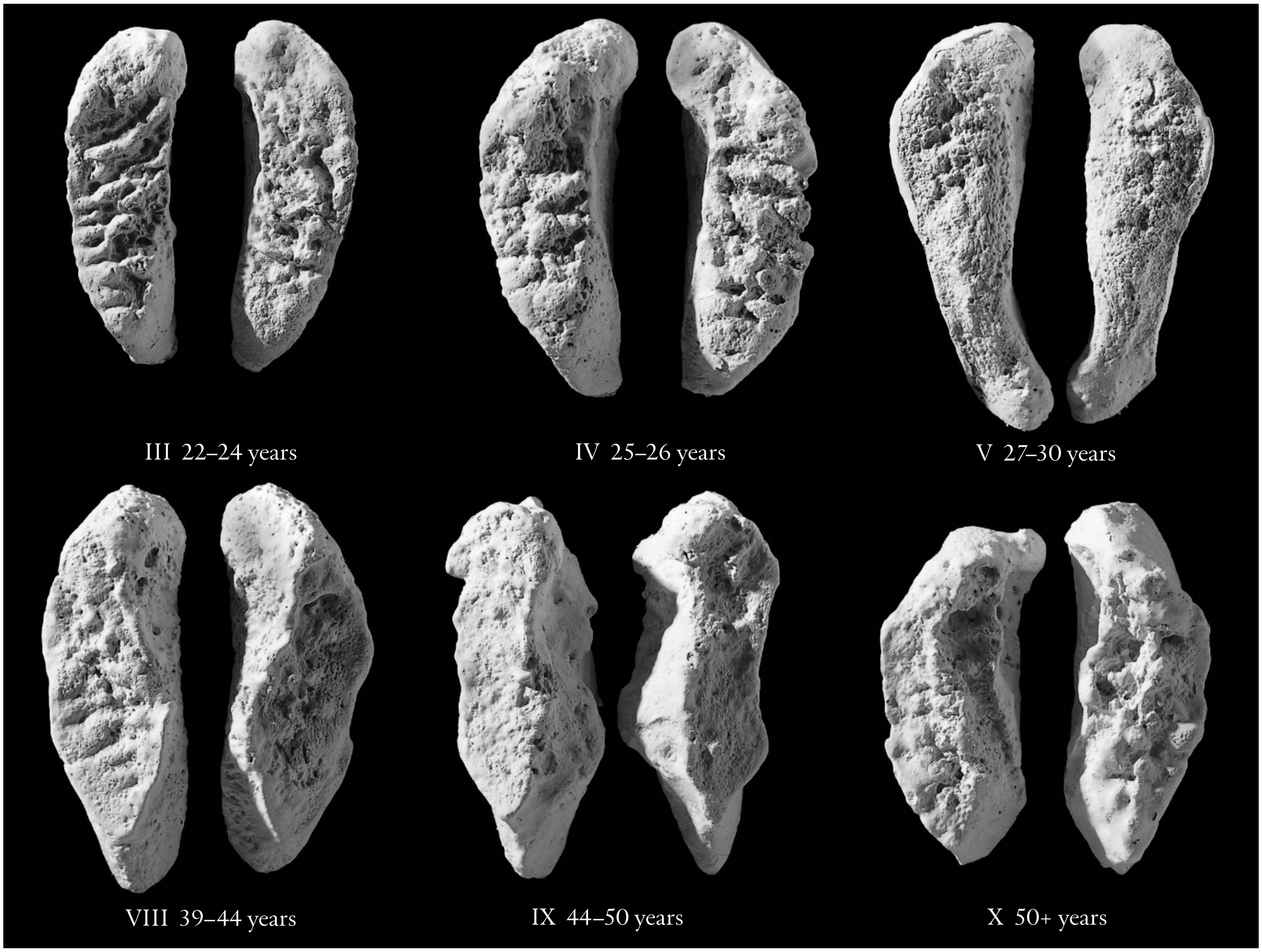


Figure 18.12 **The Todd system.** Todd's (1920) ten age phases of pubic symphysis modification in adult white males. Todd's standard specimens are shown here, natural size. The anterosuperior ends of the pubic symphyses are toward the top of the page, and the ventral margins of each symphysis pair are opposed. In the original Todd study, phases were defined according to topography on the symphyseal surface and the nature of the margins of this surface. Note the wider age ranges for the higher stages. For more details on application of the Todd technique, consult the original 1920 publication. Many newer standards have been published since this first attempt to use changes in the topography of the pubic symphysis to age the skeleton, all relying on the bony changes that correlate with age.

more recent component techniques and that all systems tended to underage. They recognize five major biological phases for the pubic symphysis and provide careful illustrative documentation of their results. They also provide a much-needed biological perspective on the metamorphosis of the pubic symphysis and assess this part of the anatomy from a comparative evolutionary background (see also Lovejoy et al., 1995, 1997).

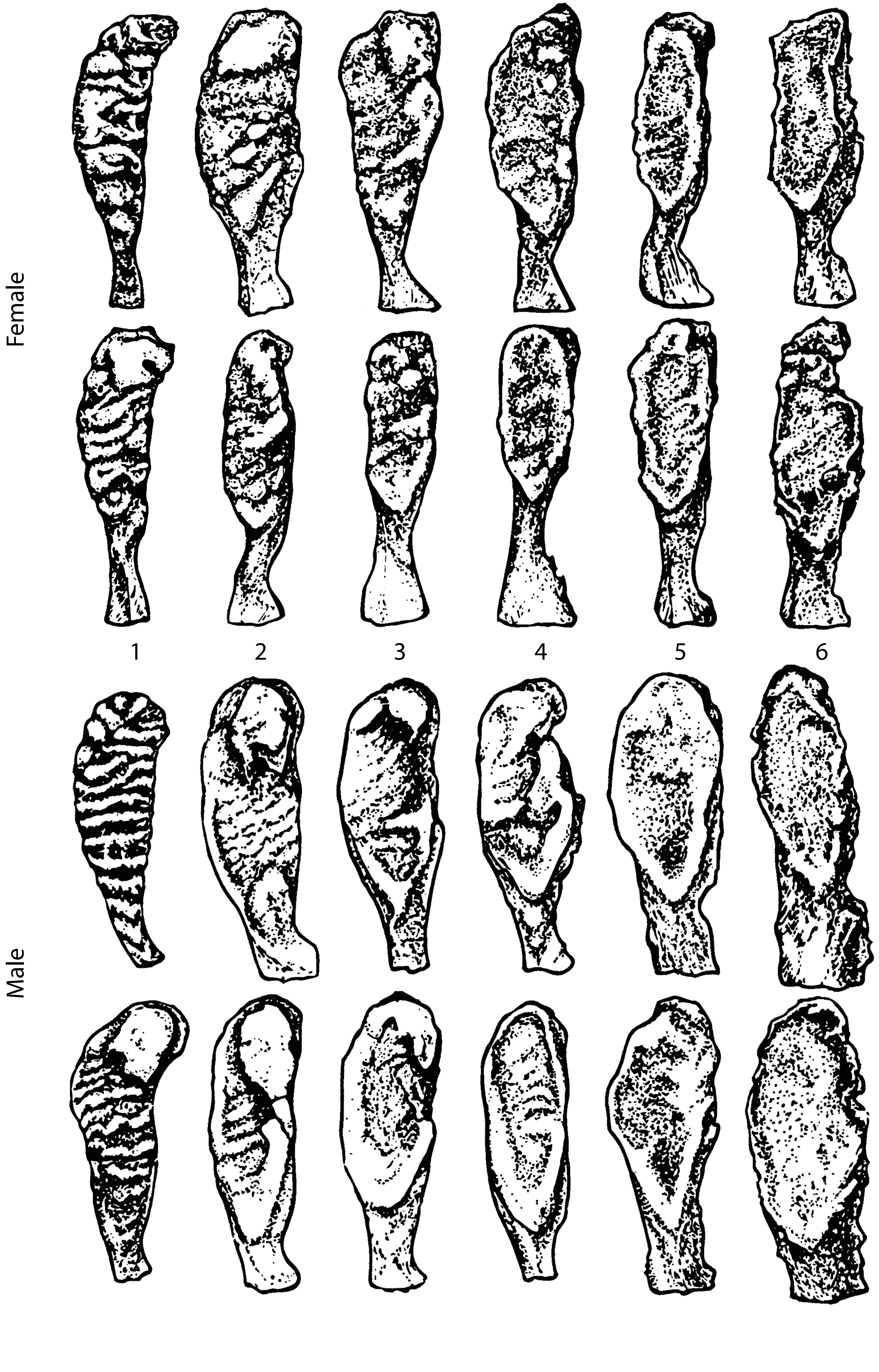
Suchey et al. (1986) and Katz and Suchey (1986), working on the large Los Angeles County Coroner multiracial sample, examined 739 male individuals between the ages of 14 and 92. These investigators contend that age-at-death data for their skeletal individuals are more accurate and precise than those used to build the Todd, McKern-Stewart, and Meindl et al. standards. The Todd and McKern-Stewart methods were tested on the Los Angeles sample and interobserver error was assessed. As a result, modifications of the earlier techniques of pubic symphysis age estimation were suggested. Katz and Suchey (1986) suggest that Todd's methodology is excellent, but that the collection he used was inadequate. They recommend the use of a modified Todd approach with six phases defined on the entire symphyseal face. Their data clearly show a large amount of variation in ages for any one phase, particularly for older individuals. For example, their Phase V shows a mean age of 51 years, but only 95% of the sample of 241 male pubic symphyses that matched this phase was within the wide age limits of 28 to 78 years.



An assessment of "race" differences among 704 of the male pubic bones was undertaken by Katz and Suchey (1989). Following implementation of the six-phase Suchey-Brooks system for male individuals, 273 female pubic bones were studied, and a system analogous to the male system was devised. Refined descriptions of the Suchey-Brooks method are found in Brooks and Suchey (1990) and in Figure 18.13. In a test of this and other pubic symphysis aging methods, Klepinger et al. (1992) concluded ". . . all the aging methods based on the os pubis proved disappointing in regard to both accuracy and precision." They recommend that the "racial" refinement of the Suchey-Brooks system be used, that any independent evidence of trauma or debilitation be considered, and that all estimated ages be reported within a standard deviation interval of plus or minus two years.

18.3.7 Parturition Changes at the Pubic Symphysis

Childbirth, or **parturition**, may result in changes on the pubic symphysis (particularly pitting adjacent to the symphysis on the dorsal edge of the pubis), auricular surface, and preauricular area of the female os coxae. To what extent can the osteologist use these changes to assess whether, or


Female
Male
1
2
3
4
5
6

how often, an individual has given birth? Studies designed to answer these questions include Kelley (1979) and Suchey et al. (1979). These studies show that up to 20% of nulliparous women display these or related features. Dorsal pitting acquired during pregnancy and childbirth may become obliterated with age. Medium-to-large dorsal pitting can occur without parturition (17 of 148 cases, Suchey et al., 1979), and parturition can occur without dorsal pitting. Four of over 700 male individuals displayed medium-to-large dorsal pitting. In short, there is a correlation between dorsal pitting of the pubis and pregnancy or parturition, but this correlation is far from perfect. The number of pregnancies cannot be predicted by the morphology of the dorsal aspect of the pubis. In a study combining humans and nonhuman mammals, Tague (1988) concludes that the severity of the resorption at the pubis is not significantly related to that of the preauricular area. Furthermore, age-at-death was shown to be significantly associated with resorption of the pubis. Cox and Scott (1992) note that pubic tubercle extension is also associated with childbirth, whereas preauricular sulci and dorsal pitting were not. Tague (1988) calls for further study of the link between estrogen and osteoclastic activity in these areas of the os coxae. Cox (2000b) provides an overview of skeletal studies of parturition, and Snodgrass and Galloway (2003) provide further critical assessment regarding forensic use of dorsal pitting.

Figure 18.13 **The Suchey-Brooks pubic symphysis scoring system.** The phase descriptions given here may be applied to either male or female symphysis faces, but matches of females should only be made in reference to the female phase types in the upper two rows. Phase descriptions are from Brooks and Suchey (1990, italics therein), and statistics for the Suchey-Brooks phases in females and males follow the descriptions; drawings are adapted by P. Walker in Buikstra and Ubelaker's Standards volume (1994) from drawings by Deborah Gray. It is recommended that these illustrations be supplemented by casts before actual aging is attempted.

Phase 1: Symphyseal face has a billowing surface (ridges and furrows), which usually extends to include the pubic tubercle. The horizontal ridges are well-marked, and ventral beveling may be commencing. Although ossific nodules may occur on the upper extremity, *a key to the recognition of this phase is the lack of delimitation of either extremity (upper or lower).*

Phase 2: The symphyseal face may still show ridge development. *The face has commencing delimitation of lower and/or upper extremities occurring with or without ossific nodules.* The ventral rampart may be in beginning phases as an extension of the bony activity at either or both extremities.

Phase 3: Symphyseal face shows lower extremity and *ventral rampart in process of completion.* There can be a continuation of fusing ossific nodules forming the upper extremity and along the ventral border. Symphyseal face is smooth or can continue to show distinct ridges. Dorsal plateau is complete. Absence of lipping of symphyseal dorsal margin; no bony ligamentous outgrowths.

Phase 4: Symphyseal face is generally fine grained although remnants of the old ridge and furrow system may still remain. *Usually the oval outline is complete at this stage, but a hiatus can occur in upper ventral rim.* Pubic tubercle is fully separated from the symphyseal face by definition of upper extremity. The symphyseal face may have a distinct rim. Ventrally, bony ligamentous outgrowths may occur on inferior portion of pubic bone adjacent to symphyseal face. If any lipping occurs, it will be slight and located on the dorsal border.

Phase 5: *Symphyseal face is completely rimmed with some slight depression of the face itself, relative to the rim.* Moderate lipping is usually found on the dorsal border with more prominent ligamentous outgrowths on the ventral border. There is little or no rim erosion. Breakdown may occur on superior ventral border.

Phase 6: *Symphyseal face may show ongoing depression as rim erodes.* Ventral ligamentous attachments are marked. In many individuals the pubic tubercle appears as a separate bony knob. The face may be pitted or porous, giving an appearance of disfigurement with the ongoing process of erratic ossification. Crenulations may occur. The shape of the face is often irregular at this stage.

Descriptive Statistics:

	Female (n = 273)			*Male (n = 739)*		
Phase	Mean	Standard Dev.	95% range	Mean	Standard Dev.	95% range
1	19.4	2.6	15–24	18.5	2.1	15–23
2	25.0	4.9	19–40	23.4	3.6	19–34
3	30.7	8.1	21–53	28.7	6.5	21–46
4	38.2	10.9	26–70	35.2	9.4	23–57
5	48.1	14.6	25–83	45.6	10.4	27–66
6	60.0	12.4	42–87	61.2	12.2	34–86

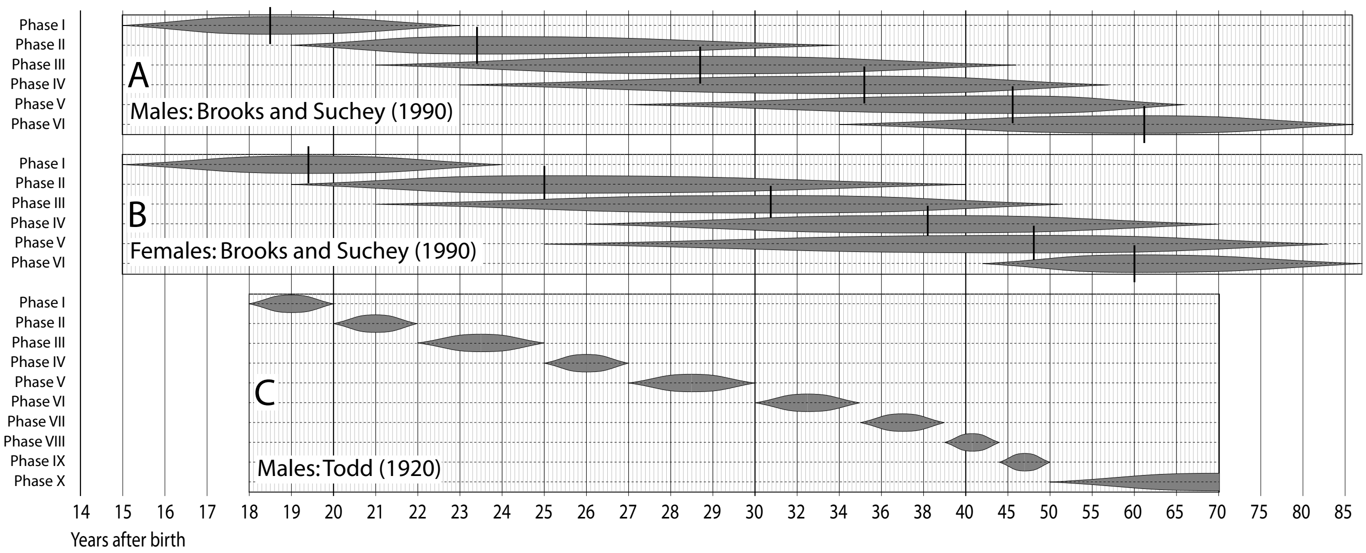


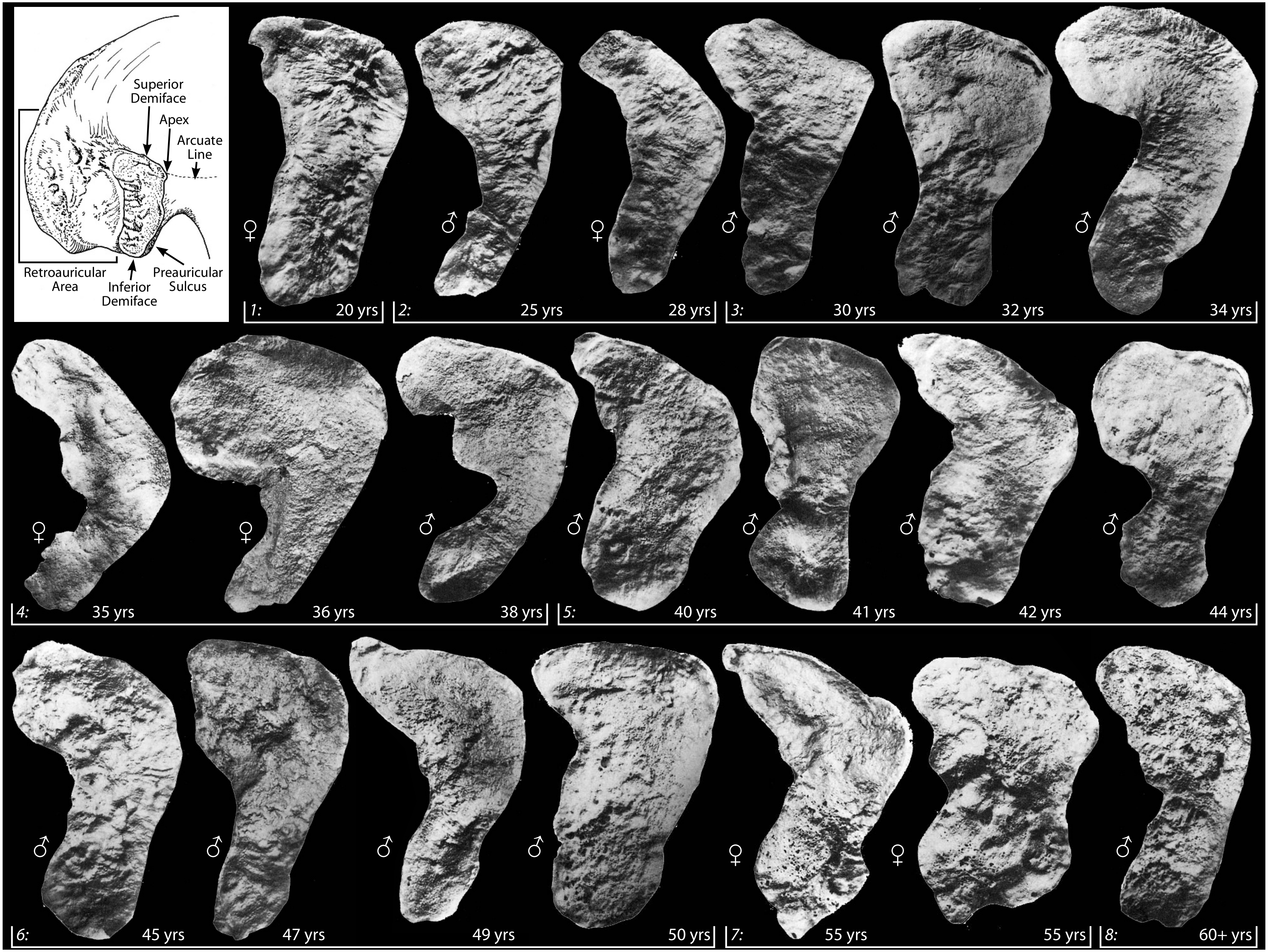
Figure 18.14 **Estimates of age that can be obtained through analysis of pubic symphyseal morphology.** **A**) Pubic symphyseal phases of males plotted against implied ages, according to the Suchey-Brooks system; **B**) symphyseal phases of females plotted against implied ages, according to the Suchey-Brooks system; **C**) symphyseal phases of males plotted against implied ages, according to the Todd system. The short black vertical lines represent mean ages for each phase (not available for C), and the gray spindles illustrate the 95% range (or, in the case of C, the published range). For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data for A and B are derived from Brooks and Suchey (1990), and data for C are derived from Todd (1920).

18.3.8 Estimating Adult Age from the Auricular Surface of the Ilium

The auricular surface of the ilium has been shown to be a reliable indicator of age in older individuals, regardless of sex or ancestry. Although it had been recognized since 1930 (Sachin, 1930) that the auricular surface changes with age, its use in predicting age at death went unexploited until 1985. In that year, Lovejoy and colleagues (1985b) published their observations on age-related changes to the auricular surface in the Hamann-Todd collection, along with a method for scoring the changes in order to place an individual in one of eight phases (Figure 18.15).

The use of the iliac auricular surface for aging individual specimens has some advantages, namely that this part of the os coxae is more likely than the pubic symphysis to be preserved in forensic and archaeological cases and that the changes on the auricular surface, unlike those on the pubic symphysis, extend well beyond the age of 50 years. Lovejoy and colleagues describe age-related changes in surface granulation, microporosity, macroporosity, transverse organization, billowing, and striations that are somewhat similar to those described for the surface of the pubic symphysis. These investigators note that auricular surface aging is more difficult to master than

Figure 18.15 *(Opposite)* **Modal changes to the auricular surface with age.** Phases described by Lovejoy et al. (1985b) as follows:
Phase 1: Age 20–24; billowing and very fine granularity
Phase 2: Age 25–29; reduction of billowing but retention of youthful appearance
Phase 3: Age 30–34; general loss of billowing, replacement by striae, coarsening of granularity
Phase 4: Age 35–39; uniform coarse granularity
Phase 5: Age 40–44; transition from coarse granularity to dense surface; this may take place over islands on the surface of one or both faces
Phase 6: Age 45–49; completion of densification with complete loss of granularity
Phase 7: Age 50–59; dense irregular surface of rugged topography and moderate to marked activity in periauricular areas
Phase 8: Age 60+; breakdown with marginal lipping, microporosity, increased irregularity, and marked activity in periauricular areas


Superior Demiface
Apex
Arcuate Line
Retroauricular Area
Inferior Demiface
Preauricular Sulcus
1: ♀ 20 yrs
2: ♂ 25 yrs ♀ 28 yrs
3: ♂ 30 yrs ♂ 32 yrs ♂ 34 yrs
4: ♀ 35 yrs ♀ 36 yrs ♂ 38 yrs
5: ♂ 40 yrs ♂ 41 yrs ♂ 42 yrs ♂ 44 yrs
6: ♂ 45 yrs ♂ 47 yrs ♂ 49 yrs ♂ 50 yrs
7: ♀ 55 yrs ♀ 55 yrs
8: ♂ 60+ yrs

the Todd method for the pubic symphysis, but they state that the potential rewards are worth the extra effort, since the method is independent of symphyseal aging but equally accurate.

The changes described by Lovejoy et al. (1985b) for the auricular surface are as follows. The young auricular surface (Figure 18.15), beginning in the first few years after postcranial epiphyseal fusion, shows a fine-grained surface texture and a pattern of regular, usually transverse surface undulations called billowing. The topography of the surface is very much like the subchondral bone of an unfused epiphysis, although the billowing is not so pronounced. Beginning in adulthood, these features of the sacroiliac joint are modified progressively and regularly as age increases. Granularity of the surface becomes coarser, billowing and striae are reduced dramatically, the original transverse organization of youth is lost, and the surface begins to display perforations of its subchondral bone, a condition known as "microporosity." In the later stages of life, the surface becomes increasingly dense and disorganized. Larger subchondral defects termed macroporosity progressively increase with age after the fifth decade. By the sixth and seventh decades, the surface has become dense, both microporotic and macroporotic, and has lost all evidence of transverse organization. Lovejoy and colleagues formalized a system of eight phases with which to classify this metamorphosis (Figure 18.15).

Buckberry and Chamberlain (2002) sought to revise the Lovejoy et al., method in order to make it easier to understand and adopt and, thus, to reduce the degree of inter- and intraobserver error that had been noted for this method (Saunders et al., 1992). Using the same features and terminology that Lovejoy et al. (1985a) established, Buckberry and Chamberlain devised a frame-

Table 18.3 **Auricular age estimates.** Scoring of iliac auricular characteristics according to the revisions of Buckberry and Chamberlain (2002)

Characteristic	Score	Description
Transverse organization	1	90% or more of surface is transversely organized
	2	50–89% of surface is transversely organized
	3	25–49% of surface is transversely organized
	4	Transverse organization is present on less than 25% of surface
	5	No transverse organization is present
Surface texture	1	90% or more of surface is *finely granular*
	2	50–89% of surface is *finely granular;* replacement of finely granular bone by coarsely granular bone in some areas; no dense bone is present
	3	50% or more of surface is *coarsely granular,* but no dense bone is present
	4	*Dense bone* is present, but occupies less than 50% of surface; this may be just one small nodule of dense bone in very early stages
	5	50% or more of surface is occupied by *dense bone*
Microporosity	1	No microporosity is present
	2	Microporosity is present on one demiface only
	3	Microporosity is present on both demifaces
Macroporosity	1	No macroporosity is present
	2	Macroporosity is present on one demiface only
	3	Macroporosity is present on both demifaces
Apical changes	1	Apex is sharp and distinct; auricular surface may be slightly raised relative to adjacent bone surface
	2	Some lipping is present at apex, but shape of articular margin is still distinct and smooth (shape of outline of surface at apex is a continuous arc)
	3	Irregularity occurs in contours of articular surface; shape of apex is no longer a smooth arc

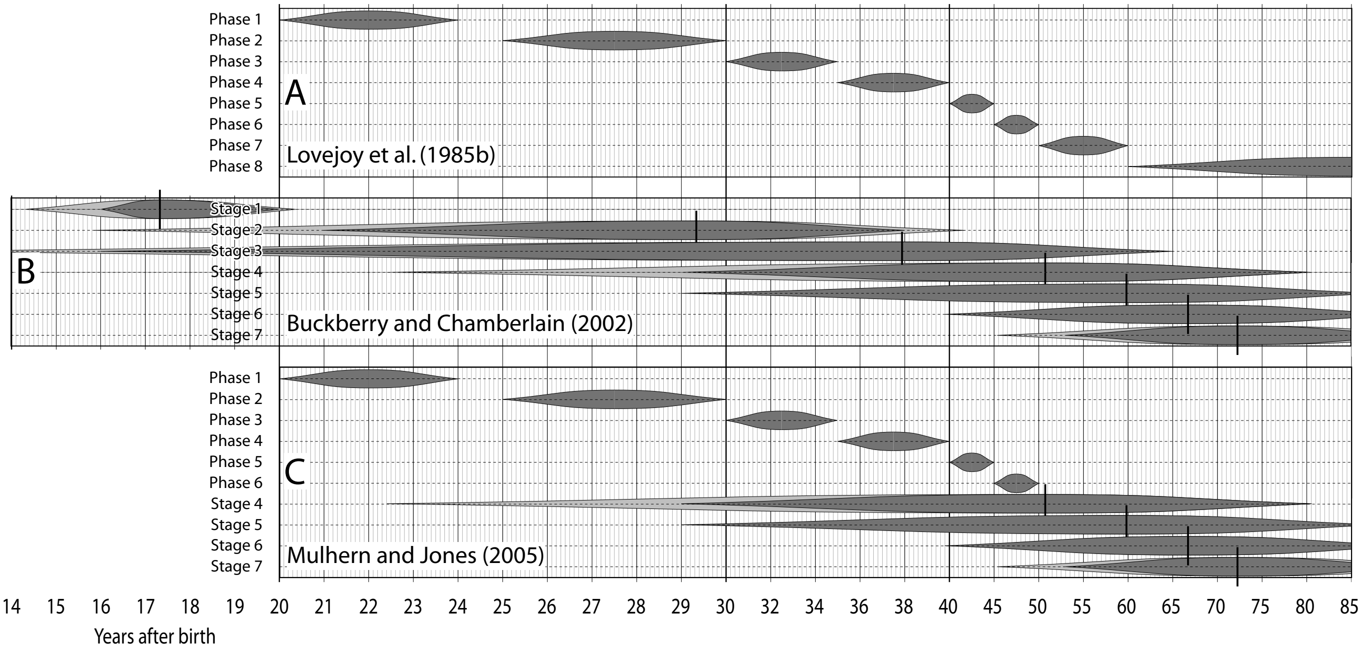


Figure 18.16 **Estimates of age that can be obtained through analysis of iliac auricular surface morphology.** **A**) Age estimates according to Lovejoy et al. (1985b); **B**) Age estimates according to Buckberry and Chamberlain (2002); **C**) Most accurate combination of these methods according to Mulhern and Jones (2005). The short black vertical lines represent mean ages for each phase, the darker gray spindles illustrate the stated ranges, and the lighter gray spindles represent ±2 SD (≅95% range). For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data for A are derived from Lovejoy et al. (1985b), data for B are derived from Buckberry and Chamberlain (2002), and data for C are derived from Mulhern and Jones (2005).

Table 18.4 **Age estimates derived from the composite scores of auricular characteristics.**
(after Buckberry and Chamberlain, 2002)

Composite score	Stage	Mean age and standard deviation	Median age	Age range
5 or 6	1	17.33 ± 1.53 years	17 years	16–19 years
7 or 8	2	29.33 ± 6.71 years	27 years	21–38 years
9 or 10	3	37.86 ± 13.08 years	37 years	16–65 years
11 or 12	4	51.41 ± 14.47 years	52 years	29–81 years
13 or 14	5	59.94 ± 12.95 years	62 years	29–88 years
15 or 16	6	66.71 ± 11.88 years	66 years	39–91 years
17, 18, or 19	7	72.25 ± 12.73 years	73 years	53–92 years

work in which each of five characteristics of the iliac auricular surface (transverse organization, surface texture, degree of microporosity, degree of macroporosity, and apical changes) are evaluated independently and given ordinal scores (Table 18.3).

Both the original method of Lovejoy et al. (1985a) and the revised method of Buckberry and Chamberlain (2002) were tested against a subset (309 individuals) of the Terry and Huntington collections at the Smithsonian Institution's National Museum of Natural History (Mulhern and Jones, 2005). Mulhern and Jones agreed with Buckberry and Chamberlain's assertions that the revised method was easier to apply and that the method appeared to be sex- and ancestry-agnostic. They found that the two methods (original and revised) had their own strengths and weaknesses and recommended that they be used only under certain conditions. The original method was found to be more accurate for individuals aged 20–49, but the revised method was found to be more accurate for individuals aged 50–69. Because the accuracy of estimates is reduced for individuals over 60 years, Mulhern and Jones recommended against using auricular surface morphology as the sole indicator of age in older adults.

18.3.9 Estimating Adult Age from the Sternal Rib End

Perhaps no other method of age determination varies so much in terms of the respect it is accorded, the accuracy it is ascribed, and the specific criteria by which it is employed as the method first announced by İşcan, Loth, and Wright (1984a, 1984b, 1985, 1986). İşcan et al. described three components of age-related change at the sternal end of the fourth rib: pit depth, pit shape, and rim and wall configuration. Six numbered stages (0–5) were described for each of these components. İşcan et al. (1984b) claimed that the method was accurate "within about 2 years in the second decade to about 7 years in the fifth and sixth decades of life."

As it stands now, this potentially important age determination method suffers from a number of problems. The method depends on both the preservation and positive identification of the fourth rib, a situation that is difficult and/or uncertain in many archaeological contexts. Work has since been undertaken on ways to identify the rib number of isolated ribs (*e.g.,* Dudar, 1993; Mann, 1993; Hoppa and Saunders, 1998; Atkas et al., 2004; Owers and Pastor, 2006), as well as assessing how well the method works on other ribs (Loth et al., 1994; Yoder et al., 2001). Other

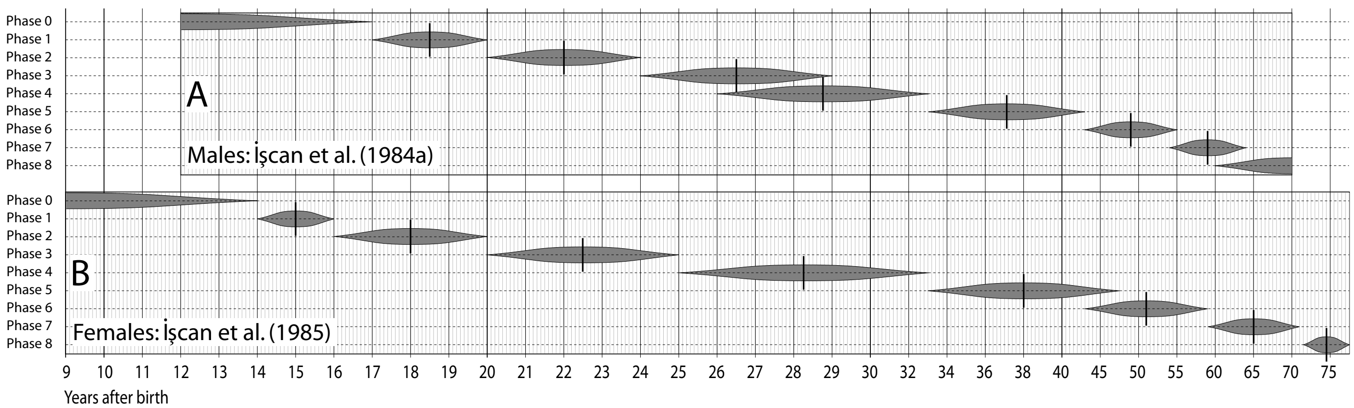


Figure 18.17 **Estimates of age that can be obtained through analysis of the morphology of the sternal end of the right fourth rib. A**) Phase-to-age relationships for males; **B**) phase-to-age relationships for females. The short black vertical lines represent mean ages for each phase, and the gray spindles illustrate the published range. For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data for A are derived from İşcan et al. (1984a), and data for B are derived from İşcan et al. (1985).

researchers have examined the more robust and uniquely identifiable first rib as a potentially better focus for aging work (Kunos et al., 1999; DiGangi et al., 2009)

The criteria used for the method are insufficiently well-defined to allow consistent application between examiners (Fanton et al., 2010), resulting in poor marks for reproducibility and repeatability, and relying heavily on the experience level of the examiner (Saunders et al., 1992). Some advocate revising the original criteria to make them clearer and more accessible to nonexperts (*e.g.,* Fanton et al., 2010), while others suggest that the criteria need to be more or less completely replaced (*e.g.,* Russell et al., 1993; Hartnett, 2010; Verlezetti et al., 2010).

In addition, the sternal rib method requires the use of separate standards for both race and sex, making application impossible unless both sex and ancestry are known. Furthermore, the applicability of the method is uncertain for individuals of non-"white" and non-"black" ancestry.

While there is much work still to be done before this technique will be of use to beginning osteologists, there is near-unanimous agreement that there is important information about age at death that is conveyed by the morphology of the sternal end of the fourth rib.

18.3.10 Estimating Adult Age by Radiographic Analysis

Changes in cancellous and cortical bone structure at macroscopic and microscopic levels take place throughout life. Walker and Lovejoy (1985) have studied this phenomenon by assessing radiographs from the Hamann-Todd collection and the prehistoric Libben collection. Using seriation, these authors describe progressive, site-specific loss of bone with age in both the clavicle and the femur. Visual seriation of radiographs showed a moderately high and significant correlation between increased age of death and decreased bone density. Macchiarelli and Bondioli (1994) show significant variation in density of the proximal femur, much of it unrelated to age. Jackes (1992) discusses problems with applications to archaeological remains.

18.3.11 Estimating Adult Age from Bone Microstructure

The normal remodeling of bone during adult life has been proposed as a condition useful for aging skeletal material. Microscopic analysis has allowed the relationships between the number of osteons and osteon fragments and the percentages of lamellar bone and non-Haversian canals to be examined. Simmons (1985), Frost (1987), and Robling and Stout (2008) provide excellent summaries of these procedures. It should be noted that these procedures are destructive to the bones under study. Many studies of histomorphometry have been undertaken on the long bones of the postcranial skeleton (for a review, see Stout, 1992). Cool et al. (1995) have shown that

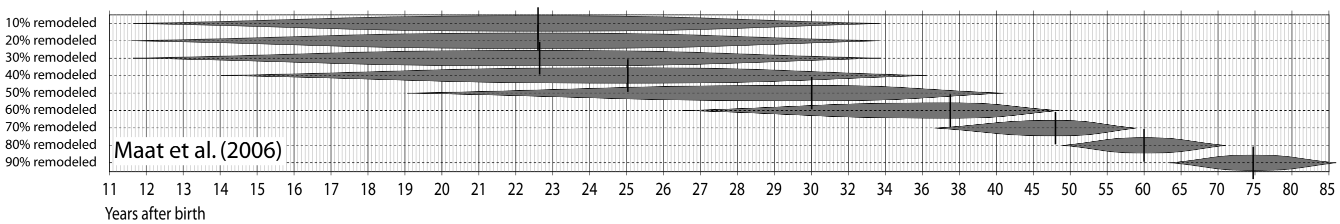


Figure 18.18 **Estimates of age that can be obtained through analysis of bone microstructure.** The degree to which older lamellar bone has been replaced by newer lamellar bone is determined by counting the number of intact and fragmentary osteons in a given area of bone. The short black vertical lines represent mean ages for each phase, and the gray spindles illustrate the ±1 SD range. For explanation of the nonlinear scale used here, see the caption to Figure 18.1. Data are derived from regression equation (for mixed sex sample) from Maat et al. (2006: 233).

histomorphological variables of the human occipital were less reliable than those of the long bones for estimating age.

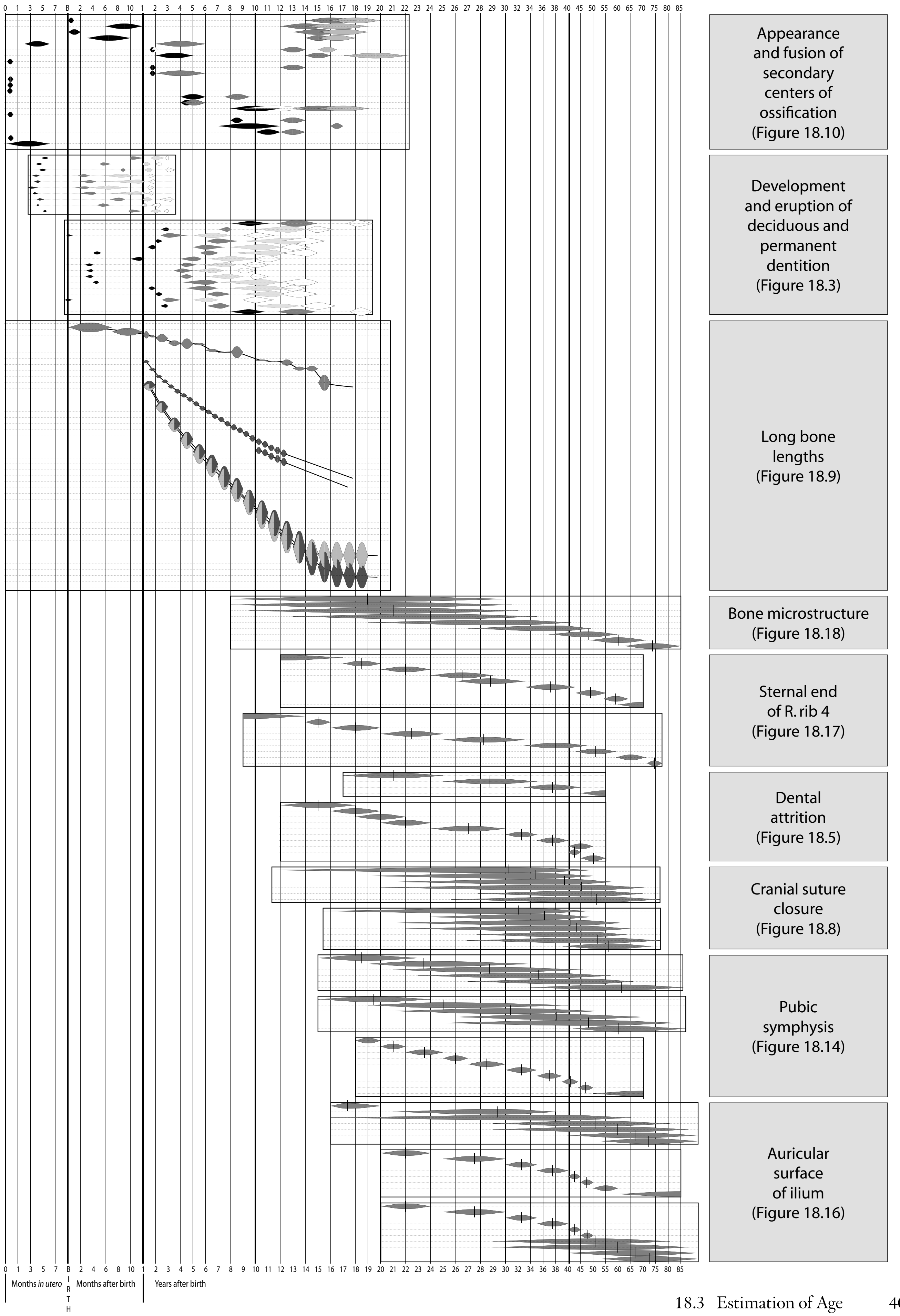
All of these methods are quantitative and depend on osteonal remodeling of bone and accumulated osteon populations. Many factors can influence this process and its products, including sex, hormones, mechanical strain, and nutrition. Remodeling is the sequential removal and replacement of older lamellar bone with newer lamellar bone. It takes place throughout the life span. Histological analysis of tissue from selected sites on the skeleton (including the ribs and clavicle: Stout and Paine, 1992; Stout et al., 1994, 1996) has shown an association between age-at-death and the number of observable osteons per unit area in a cross-section. The number of intact and fragmentary osteons per unit area is calculated for each bone (normally for at least two slices of each bone), and the result is put into regression equations that calculate the age. Stout (1992) identifies a variety of problems with the technique as applied by different investigators, and calls for more research in the forensic setting. Pfeiffer et al. (1995) and others have found that histological profiles vary by sample location, something that must be controlled for in application of these techniques. As Ericksen (1991) notes, it is critical that osteologists using bone microstructure to age archaeological specimens be very cautious about pre-analysis exfoliation of unremodeled peripheral lamellae on bones. Jackes (1992) notes other complicating factors for the use of these techniques on archaeological remains. Aiello and Molleson (1993) compared pubic symphyseal aging to microscopic aging techniques and found neither to be more accurate. Wallin and colleagues (1994: 353) have found that their determination of age-at-death through microscopic bone morphometry resulted in standard deviations of over 12 years and was "considerably less precise than generally stated in the literature." Paine and Brenton (2006) found that poor nutritional health significantly retards osteonal remodeling, resulting in the under-aging of individuals by an average of 29.2 years.

18.3.12 Multifactorial Age Estimation

Given the variety of techniques available for assessing skeletal age-at-death (for another review, see Cox, 2000a), what techniques should be used by the osteologist? In Todd's original 1920 work on the changes he had classified in the pubic symphysis, he took great pains to point out that the most accurate estimate of age can only be made after examination of the entire skeleton. However, due to the sometimes fragmentary nature of skeletal remains and the history of development of aging techniques, his advice has often been subsequently forgotten by human osteologists. All osteologists use dental development, eruption, epiphyseal appearance, and fusion when aging immature skeletal material. For aging adult skeletal remains, however, osteologists are sharply divided on the question of technique. This controversy provides an important arena for the continued testing and refinement of the techniques outlined earlier.

Some osteologists, particularly those working in forensic contexts, favor the use of the pubic symphysis and assign other anatomical regions a lesser role in age analysis. Lovejoy et al. (1985a) note that this traditional forensic orientation to aging has led to problems when skeletons from large populations are aged by different observers using established methods. Furthermore, the value of skeletal age indicators has been judged on the basis of accuracy (differences between predicted and actual ages) without due regard to bias (the tendency of a given technique to over- or under-age).

Figure 18.19 (*Opposite*) **A visual comparison of age estimates based on various techniques.** Refer to the individual figures for additional details and data sources. For explanation of the nonlinear scale used here, see the caption to Figure 18.1.


0 1 3 5 7 B 2 4 6 8 10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 32 34 36 38 40 45 50 55 60 65 70 75 80 85
Months *in utero*
BIRTH
Months after birth
Years after birth
Appearance and fusion of secondary centers of ossification (Figure 18.10)
Development and eruption of deciduous and permanent dentition (Figure 18.3)
Long bone lengths (Figure 18.9)
Bone microstructure (Figure 18.18)
Sternal end of R. rib 4 (Figure 18.17)
Dental attrition (Figure 18.5)
Cranial suture closure (Figure 18.8)
Pubic symphysis (Figure 18.14)
Auricular surface of ilium (Figure 18.16)

If more than one criterion is available for assessing skeletal age-at-death, all criteria should be employed (Baccino et al., 1999). One immediate objection to this recommendation arises because of the marked differences in the reliability between different age indicators. For example, many investigators are hesitant to alter a determination of age-at-death based on the pubic symphysis given additional data from cranial suture closure because of the perceived unreliability of the latter (see Meindl and Lovejoy, 1985). In forensic aging of single individuals, such caution may be advisable (depending on the assessed age). However, cranial suture closure is correlated with increasing age, and in the analysis of populations the addition of data on age-at-death from the sequential addition of other age indicators should improve the accuracy of determination.

18.4 Determination of Sex

The terms "sex" and "gender" have increasingly become conflated in the anthropological and medical literature. They do not refer to the same thing, they are not synonyms, and they should not be used interchangeably. Gender is an aspect of a person's social identity, whereas sex refers to a person's biological identity. This distinction is important for biological anthropologists to preserve in general, and particularly important to retain in human osteology (Walker and Cook, 1998). In the archaeological context, it is often possible to determine sex through analysis of skeletal remains, and gender roles through studies of material culture (artifacts) and context.

With a sample of 50 lowland gorilla males and 50 lowland gorilla females, even the untrained observer could sort skeletal elements by sex using size and shape. For this primate, 100% accuracy in sorting is obtained easily. The same applies to orangutans. With chimpanzees, the differences are not as marked, but when the canine teeth rather than the overall size of the cranium are examined, perfect accuracy can still be approached. Moving to a sample of 50 male and 50 female modern humans, there is far less sexual dimorphism in canine size, and sorting accuracy is therefore reduced. For some elements, such as the pelvis or the cranium, training and experience can often allow correct sorting about 80–90% of the time. Because of the uncertainties involved in the determination of sex from human skeletal remains, a vocabulary of terms (Table 18.5) which express both the determination of sex and the analyst's confidence in the determination will prove useful.

Table 18.5 **Terminology and abbreviations used in determinations of sex**

<table>
<tr><th colspan="2">Term and symbol</th><th>Should be read as</th><th>Meaning</th></tr>
<tr><td>Female</td><td>♀</td><td>Female</td><td rowspan="2">Analyst has full confidence in the determination of sex for the remains.</td></tr>
<tr><td>Male</td><td>♂</td><td>Male</td></tr>
<tr><td>(Female)</td><td>(♀)</td><td>Probably female</td><td rowspan="2">Analyst does not have full confidence in the determination, but feels the remains are probably the stated sex.</td></tr>
<tr><td>(Male)</td><td>(♂)</td><td>Probably male</td></tr>
<tr><td>Female ?</td><td>♀ ?</td><td>Possibly female</td><td rowspan="2">Analyst does not have confidence in the determination, but feels the available evidence hints at the stated sex.</td></tr>
<tr><td>Male ?</td><td>♂ ?</td><td>Possibly male</td></tr>
<tr><td colspan="2">indet.</td><td>sex indeterminate</td><td>The remains have been analyzed, but are lacking sufficient diagnostic morphology for a determination of sex.</td></tr>
<tr><td colspan="2">unk.</td><td>unknown sex</td><td>The remains have not been analyzed; no determination of sex has been attempted.</td></tr>
</table>

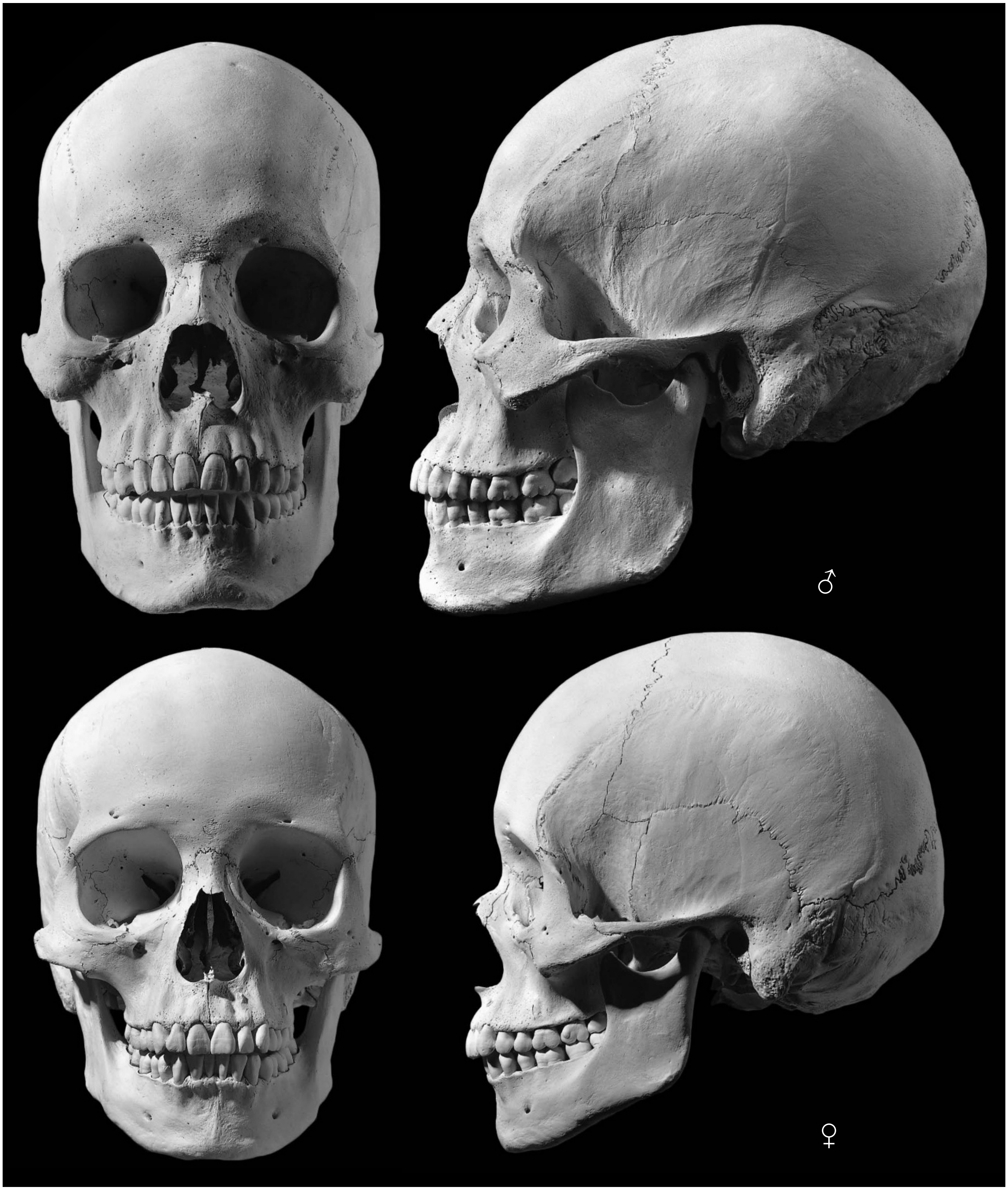


Figure 18.20 **Male** (*top*) **and female** (*bottom*) **adult skulls in frontal and lateral views**. The female skull chosen for this illustration was taken from the hyper-feminine end of the female range. The male is the same individual used to illustrate the cranium in Chapter 4. This comparison illustrates the differences between male and female skulls discussed in the text. It should *not* be taken as a representation of the difference between *average* male and female skulls, but rather as an indication of how much sexual variation is seen in the human skull. One-half natural size.

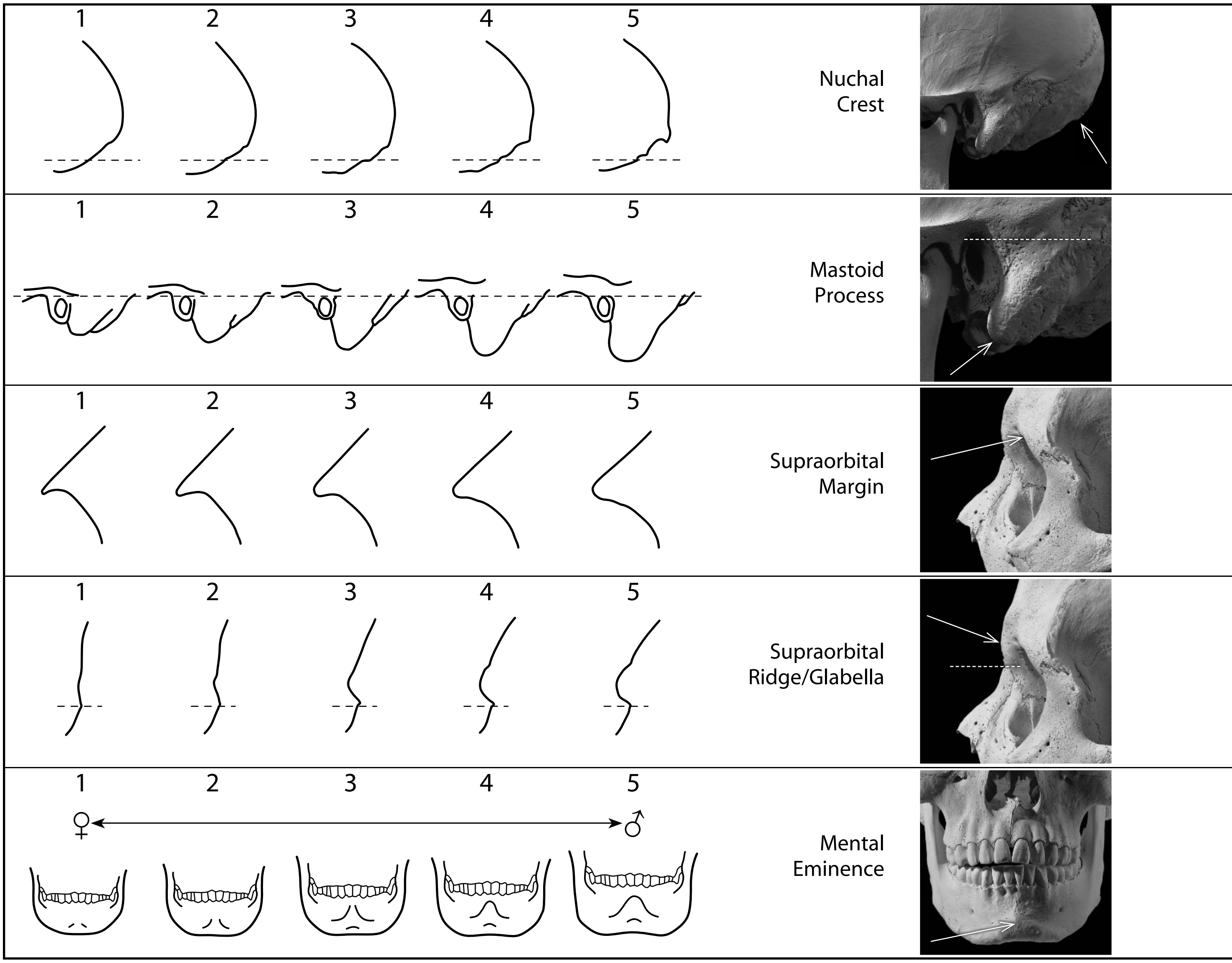


Figure 18.21 **Cranial sexing**. A qualitative scoring system for sexually dimorphic cranial features from Walker in Buikstra and Ubelaker (1994). In recording the features, optimal results are obtained by holding the cranium or mandible at arm's length, a few inches above the appropriate portion of this figure, oriented so that the features can be directly compared with those illustrated. Move the bone from diagram to diagram until the closest match is obtained. Score each trait independently, ignoring other features. A specific procedure is described to the right of each trait (revised after Walker, 2008). *Key:* 1 = hyperfeminine, 2 = feminine; 3 = indeterminate; 4 = masculine; 5 = hypermasculine.

Human sexual dimorphism is complex, with behavioral, physiological, and anatomical dimensions. Anatomical differences are more pronounced in some soft tissue areas, but much more limited in the skeleton. Nevertheless, skeletal differences between male and female humans do exist and can be useful to the osteologist. It is important to keep in mind that determinations of sex for human skeletal remains are most accurate after the individual reaches maturity. Buikstra and Mielke (1985) summarize in helpful tabular form the accuracy of a variety of skeletal sexing techniques, and Mays and Cox (2000) provide a review of techniques for mature and immature remains.

Nuchal Crest: View the lateral profile of the occipital and compare it to the diagrams. Feel the surface of the occipital and note any rugosities on its surface. The important feature to consider in scoring this trait is the development of bone on the external surface of the occipital associated with the attachment of the nuchal muscles. Ignore the contour of the underlying bone (*e.g.,* the presence or absence of an occipital bun) in scoring this trait.
Minimal expression (score = 1): The external surface of the occipital is smooth with no bony projections visible from when the lateral profile of the occipital is viewed.
Maximal expression (score = 5): A massive nuchal crest that projects considerable distance from the bone and forms a well-defined ledge or hook of bone.

Mastoid Process: Score this feature by comparing its size with that of surrounding structures such as the external acoustic meatus and zygomatic process of the temporal bone. Mastoid processes vary considerably in their proportions. The most important variable to consider in scoring this trait is the volume of the mastoid process, not its length.
Minimal expression (score = 1): A very small mastoid process that projects only a small distance below the inferior margins of the external acoustic meatus and the digastric groove.
Maximal expression (score = 5): A massive mastoid process with lengths and widths several times that of the external acoustic meatus.

Supraorbital Margin: Hold your finger against the margin of the orbit in the area lateral to the supra-orbital foramen. Look at each of the diagrams to determine which matches most closely.
Minimal expression (score = 1): Extremely sharp, border feels like the edge of a dull knife.
Maximal expression (score = 5): A thick rounded margin with a curvature that approximates that of a pencil.

Glabella/Supraorbital Ridge: View the cranium from its lateral side and compare the profile of the glabella/supra-orbital area with the profiles in the diagrams.
Minimal expression (score = 1): The contour of the frontal is smooth with little or no projection in the glabellar area.
Maximal expression (score = 5): The glabella and/or supra-orbital ridge are massive and from a rounded loaf-shaped projection.

Mental Eminence: Hold the mandible between your thumbs and your index fingers with your thumbs on either side of the mental eminence. Move your thumbs medially so that they delimit the lateral borders of the mental eminence.
Minimal expression (score = 1): Area of the mental eminence is smooth. There is little or no projection of the mental eminence above the surrounding bone.
Maximal expression (score = 5): A massive mental eminence that occupies most of the anterior portion of the mandible.

In general and within a given population, female skeletal elements are characterized by smaller size and lighter construction. For this reason, in a large, seriated, mixed-sex collection of elements, the largest, most robust elements with the heaviest rugosity are male. Males can be, on average, up to 20% larger in some skeletal dimensions, whereas in other dimensions there may be no dimorphism. The smallest, most gracile elements are normally female. Normal individual variation, however, always produces some small, gracile males and some large, robust females who fall toward the center of the distribution where sorting sex is difficult. In other words, the sexes overlap near the center of the distribution. For this reason, osteologists have traditionally concentrated on elements of the skull and pelvis in which sex differences in humans are the most extreme.

In addition to the complications of individual variation within the population, incorrect sex identifications are sometimes made because of variation among populations. Some populations are, on average, composed of larger, heavier, more robust individuals of both sexes, whereas other populations are characterized by the opposite tendency. Because of such interpopulational differences in size and robusticity, males from one population are sometimes mistaken for females in other populations and vice versa. The osteologist should always attempt to become familiar with the skeletal sexual dimorphism of the population from which unsexed material has been drawn. As it is with aging, seriation can be a helpful approach in determining the sex of skeletal remains from a population.

All of the morphological techniques used in sexing skeletal remains depend on the preservation of sexually dimorphic elements. All of them share a nontrivial error rate, even for adult remains. However, if DNA can be recovered from osseous remains, the sex of any individual (regardless of individual age) can be determined with high accuracy. This is true even for highly fragmentary remains. Sexing of osteological specimens in a forensic context, therefore, has been changed fundamentally by the introduction of molecular techniques to human osteology (Stone et al., 1996; Stone, 2000, 2008).

18.4.1 Sexing the Skull Using Overall Robusticity

Determination of sex based on parts of the skull follows the observation that males tend to be larger and more robust than females. In addition to size, tendencies such as those outlined here provide useful indications for determining the sex of isolated skulls. These characteristics are the traditional ones used by osteologists. Figure 18.20 illustrates them.

Relative to female crania, male crania are characterized by greater robusticity. Male crania typically display more prominent supraorbital ridges, a more prominent glabellar region, and heavier temporal and nuchal lines. Male frontals and parietals tend to be less bossed than female ones. Males tend to have relatively large, broad palates, squarer orbits, larger mastoid processes, larger sinuses, and larger occipital condyles than females. When compared to female mandibles, male mandibles are characterized by squarer chins, more gonial eversion, deeper mandibular rami, and more rugose muscle attachments (*e.g.,* see Gülekon and Turgut, 2003).

The relative strength of these cranial tendencies can be summarized by the following: Where associated postcranial material is available, always use the pelvis for sex determination. When sexing only skulls, always use the entire population under study. Seriate this population according to the criteria you use and then sort. If you are sexing only one or a few individuals, try to use comparative populations that are genetically and temporally close to the ones from which your sample derives.

Walker, in the Buikstra and Ubelaker Standards volume (1994), provides five aspects of skull morphology that are useful in determining sex. These are shown in Figure 18.21. In all cases, a five-point scale is used, to be interpreted as follows: 1 = hyperfeminine, 2 = feminine; 3 = indeterminate; 4 = masculine; 5 = hypermasculine. Graw et al. (1999) present another scoring system focused only on the supraorbital margin and Walrath et al. (2004) warn that the degree of reliability for such methods is closely linked to the clarity and quality of the definitions provided for scoring the characteristics.

In an attempt to go beyond the traditional methods outlined earlier, Giles and Elliot (1963) used discriminant functions based on nine standard cranial metrics to diminish the subjectivity involved in sexing the skull. However, a study by Meindl et al. (1985b) has shown that subjective assessment of the skull compared favorably to the discriminant functions of Giles and Elliot. In tests on Hamann-Todd crania, Meindl et al. (1985b) found that older individuals show increasingly "masculine" morphology. Whereas 10.2% of the males in their sample of 100 were sexed incorrectly, only 4.9% of the females were misidentified. Given these facts, Meindl et al. (1985b) suggest that overall sex ratios and age class sex ratios in prehistoric cemeteries should only be estimated from adult burials with fully preserved pelves.

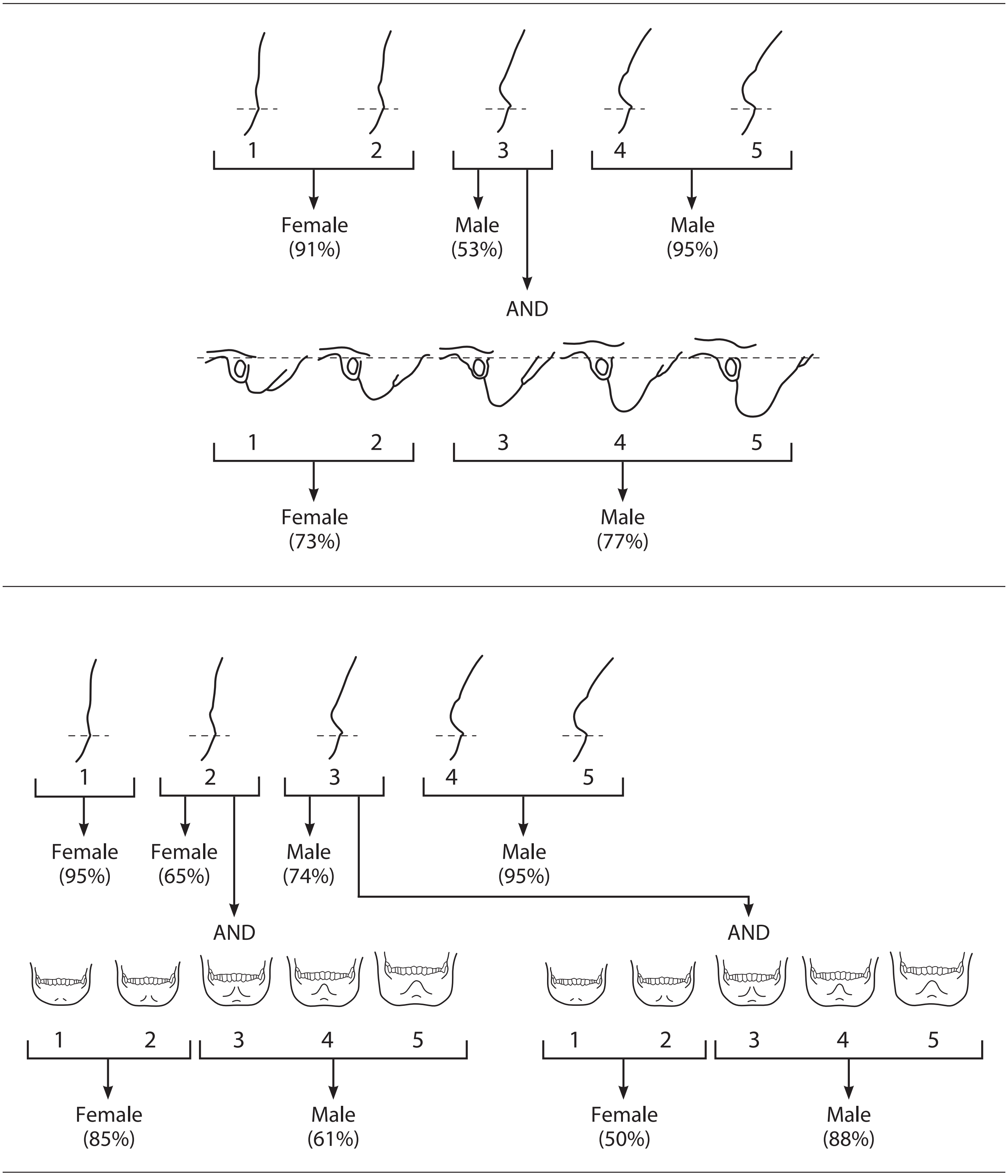


Figure 18.22 **CHAID analysis decision trees.** Two examples demonstrating the use of decision analyses in probabilistic sex determination (Stevenson et al., 2009). *Top:* the classification tree shown on the top is for European Americans crania which preserve both glabella (*above*) and mastoid process (*below*). *Bottom:* the classification tree on the bottom is for a mixed sample of Europeans, European Americans, and African Americans which preserve both glabella (*above*) and the mental eminence (*below*). Based on data from Stevenson et al. (2009).

A promising new technique has been introduced which can be used with ordinal data such as that obtained when scoring cranial traits according to Walker's system, discussed above. Using Chi-squared automatic interaction detection (CHAID), Stevenson et al. (2009) were able to produce classification trees that are easy to use and result in a probabilistic determination of sex (see Figure 18.22 for two examples of such decision trees).

18.4.2 Sexing the Mandible

In addition to the robusticity of the mental eminence discussed above, there are other sexually dimorphic traits that can be used to determine the sex of isolated mandible. Males tend to have gonial angles that are rugose and often everted, both as a consequence of having larger masseter muscles (Acsádi and Nemeskeri, 1970; Novotný, et al., 1993; Kemkes-Grottenthaler et al., 2002). Females and immature individuals of both sexes have more gracile gonial angles that are not everted.

Loth and Henneberg (1996, 1998) proposed that the posterior border of the mandibular ramus could be used to sex unknowns with a predictive accuracy of about 90.6% – 99.0%. They noted that mandibles of adult males have a distinct angulation of the posterior border of the mandibular ramus at the level of the occlusal surface of the molars, and that females lacked flexure at that level (Figure 18.23). The technique was scrutinized by Koski (1996), Donnelly et al. (1998), Haun (2000), Hill (2000), and Kemkes-Grottenthaler (2002), and was found to yield results with much lower accuracy (59% – 80.4%); but more recently, Balci et al. (2005) reexamined the method and found a base level of 90.6% accuracy that was higher in males (95.6%) than in females (70.6%).

Balci et al. (2005) noted that all previous tests of the method had not followed Loth and Henneberg's caution against including mandibles with excessive tooth loss (ETL), and they proposed that any mandible missing more than two molars should be excluded on the basis of ETL. Balci et al. were able to increase the accuracy of the method even further when they broadened the definition of "sex indeterminate" from just a score of 0 to a score of –1, 0, or +1. With these ambiguous mandibles removed from the analysis — thereby limiting the analysis to only those mandibles having either bilateral flexure (score = +2) or bilateral nonflexure (score = –2) — the accuracy of the modified method *on the remaining mandibles* rose dramatically (to 100% in their

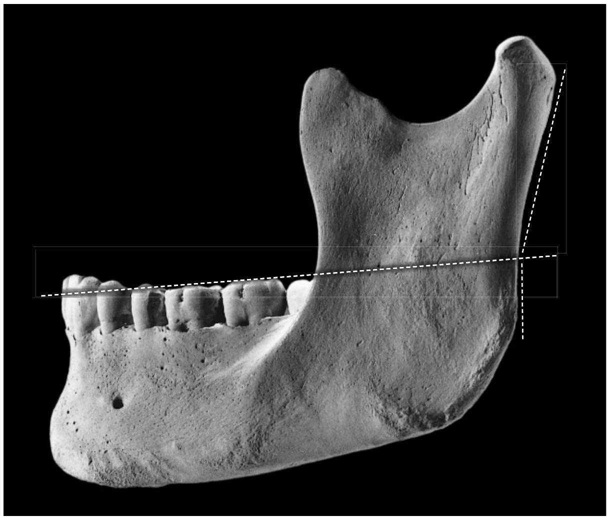


Figure 18.23 **Ramal flexion**. Flexure of the posterior border of the mandibular ramus in a young male individual. In contrast to males, who have a pronounced flexure of the posterior ramal border at the level of the occlusal surface of the molars, females tend to have either a straight posterior ramal border or a flexure that is close to the condylar neck. The individual shown here is the same one used to illustrate Chapter 4. Two-thirds natural size.

sample). It should be noted that the trade-off for such high accuracy is a substantially reduced applicability—of the 120 mandibles Balci et al. examined, sex could be assigned to only 69 or 57.5% (males: 67.4%, females: 20.0%). As their sample is taken from a modern study collection, one could expect that the applicability would be even lower for archaeological remains.

Loth and Henneberg (2001) also claimed that their posterior ramal flexure method could be used to determine sex in juveniles with 81% accuracy, but in a blind test of the method on juvenile mandibles, Scheuer (2002) found the accuracy to only be 64%.

18.4.3 Sexing the Teeth

Because teeth are often better preserved than other skeletal elements, there have been efforts to sex the skeleton using the teeth. The degree of sexual dimorphism in human crown sizes varies between populations. Human dental dimorphism centers on the canines, but it is not nearly so pronounced as it is in the great apes. Human lower canines show the greatest dimorphism, up to 7.3% (Hillson, 1996, 2005), followed by the upper canines. Deciduous teeth are also dimorphic, with molars and canines up to 7%. Accuracy of sexing unknowns based on dental metrics, either univariate or multivariate, varies from 60% to 90% and usually lies between 75% and 80%. Because the average difference in size between sexes at any individual tooth position is very small, about half a millimeter on average, these dimensions must be measured carefully and with precise instruments, to avoid intra- and interobserver error. De Vito and Saunders (1990), Bermúdez de Castro et al. (1993), Beyer-Olsen and Alexandersen (1995), and Hillson (1996, 2005) provide reviews of the use of dental dimensions to sex human teeth.

18.4.4 Sexing the Postcranial Skeleton

As for the cranium, sexually diagnostic traits in the postcranial skeleton are difficult to identify and assess before puberty. Numerous metric studies of the postcranial skeleton have examined sexual dimorphism in the size of different adult elements. Bass (2005) provides an excellent review of these. Results on the most dimorphic limb bones can be summarized by noting that single measurements, or combinations of measurements, have usually been found to correctly identify the sex of between 80% and 90% of all individuals. Incorrect identification within any population is a consequence of size overlap between males and females in the center of the overall range (Figure 18.24). Many studies have been conducted on known-sex samples to derive functions capable of classifying sex accurately more than 85% of the time for a variety of elements ranging from the metacarpals (Falsetti, 1995; Stojanowski, 1999; but see Burrows, 2003) to the metatarsals (Robling and Ubelaker, 1997), humerus (Rogers, 1999), ulna (Purkait, 2001), and calcaneus (Introna et al., 1997). Because these functions are often not tested beyond (or independent of) the skeletal population on which they were based, claims of accuracy are sometimes questionable. For instance, Rogers (1999) has claimed 92% accuracy based on four characters of the distal humerus, but testing on a wider sample will be required.

The skull was the first, most traditional focus of sexing studies, but a number of methods of sexing have also been applied to the pelvis. There are dramatic functional differences between male and female pelvic anatomy. These extend to the bony skeleton and represent differences found in all modern human groups. The pelvis is of vital importance in locomotion and parturition. During human evolution, selective pressures associated with these and other roles led to the sexual dimorphism seen in the modern human pelvis.

Traditional methods used to determine sex on the pelvis or its parts are based on the following tendencies: The sacra and ossa coxae of females are smaller and less robust than those of males. Female pelvic inlets are relatively wider than male ones. The greater sciatic notches on female ossa coxae are relatively wider than those on male bones (Figure 18.25). Females have relatively longer pubic portions of the os coxae, including the superior pubic ramus, than males. The subpu-

Figure 18.24 **Variation in tibial size and shape among ten females** (*above*) **and ten males** (*below*)**.** Tibiae were selected at random from a single-site, sex-balanced sample of 100 prehistoric Californian skeletons. This sample, 20% of the total population, gives an indication of the normal sexual dimorphism encountered in modern human skeletal remains. One-sixth natural size.

bic angle, formed between the lower edges of the two inferior pubic rami, is larger in females than in males. The preauricular sulcus is present more often in females than in males. A corollary is that the auricular surface is more elevated from the female ilium than from the male ilium, even though sexual dimorphism in the auricular surface itself is insufficient for accurate sexing (Ali and MacLaughlin, 1991). The acetabulum tends to be relatively larger in males (Figure 18.26).

A variety of metric techniques have been developed to express these relationships. Washburn's attempt to quantify the relative proportion of the pubic part of the os coxae is the most famous and effective of these. Washburn (1948) measured the length of the pubis relative to the length of the ischium via an index that discriminated between male and female ossa coxae. Rogers and Saunders (1994) provide a review of metric and morphological traits used to sex the pelvis, and

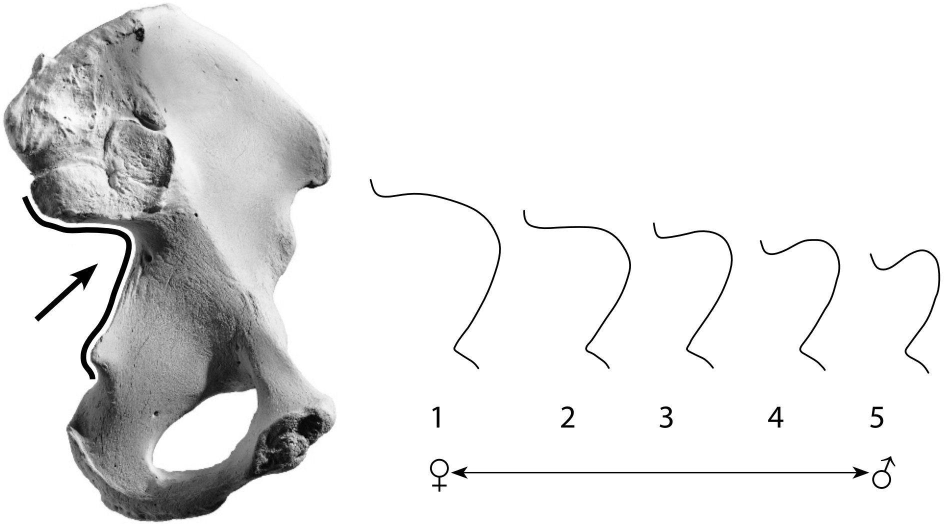


Figure 18.25 **Sex differences in the greater sciatic notch.** From P. Walker in Buikstra and Ubelaker's Standards volume (1994). The greater sciatic notch tends to be broad in females and narrow in males. These shape differences are not as reliable as those in the subpubic region and should be thought of as secondary indicators. The best results for scoring are obtained by holding the os coxae above this figure so that the greater sciatic notch has the same orientation as the outlines, aligning the straight anterior portion of the notch that terminates at the ischial spine with the right side of the diagram. While holding the bone in this manner, move it to determine the closest match. Ignore any exostoses near the preauricular sulcus and the inferior posterior iliac spine. Configurations more extreme than 1 or 5 should be scored as 1 and 5, respectively. The illustration numbered 1 shows typical female morphology, whereas the higher numbers are male conformations.

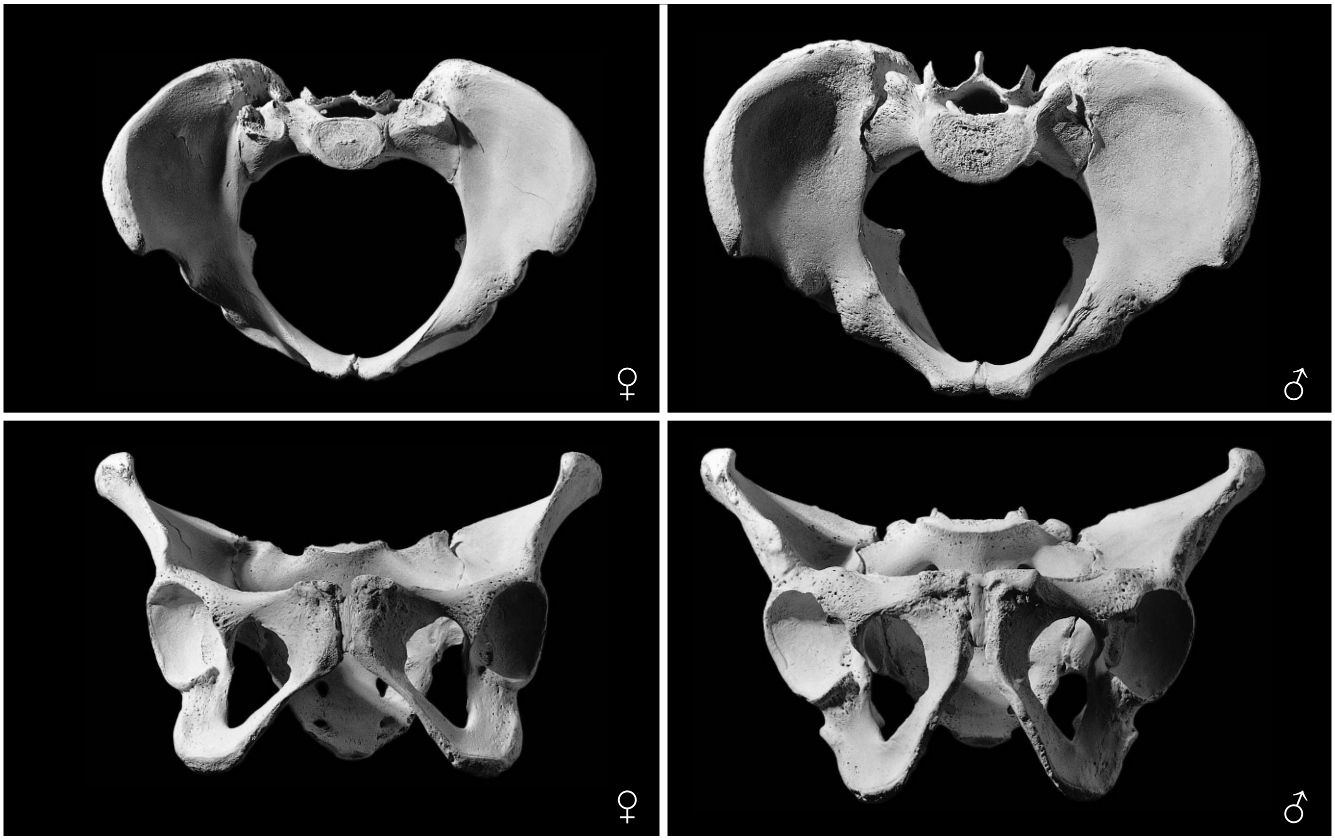


Figure 18.26 **Sexual dimorphism in the bony pelvis showing differences in size and shape.** *Left:* female; *right:* male. One-fourth natural size.

Brůžek (2002) provides a more current assessment. Walker's (2005) analysis of age and population variation in sciatic notch form is a valuable review.

In 1969, T. W. Phenice published an important new method for sexing the pelvis. This paper, "A newly developed visual method of sexing the os pubis," described the most accurate method yet known for determining sex of an individual from the skeleton. Until the publication of the Phenice paper, the osteologist's success at using traditional visual methods of sexing the pelvis depended, in large part, on experience—decisions were more-or-less subjective. The application of metric criteria was difficult because many pelves were not intact enough for reliable measurement, and even the simplest techniques were time-consuming. Phenice's method (Figure 18.27) changed the situation, allowing more accurate, quicker sexing on any pelvis bearing an intact pubic region.

In employing the Phenice method to sex an os coxae, note that not every specimen is a "perfect" male or female. When there is a criterion that does not obviously sex the specimen, discard that criterion. When there is some ambiguity concerning one or two of the criteria (most often in the medial aspect of the ischiopubic ramus, and least often in the ventral arc), usually one of the remaining criteria will clearly attribute the specimen to a sex. After sexing the specimen with this procedure, observe the more traditional features outlined earlier to see if they correspond to (corroborate) your diagnosis. For any case in which they do not confirm, recheck your observations. Remember that female individuals are most likely to be intermediate in displaying the Phenice features.

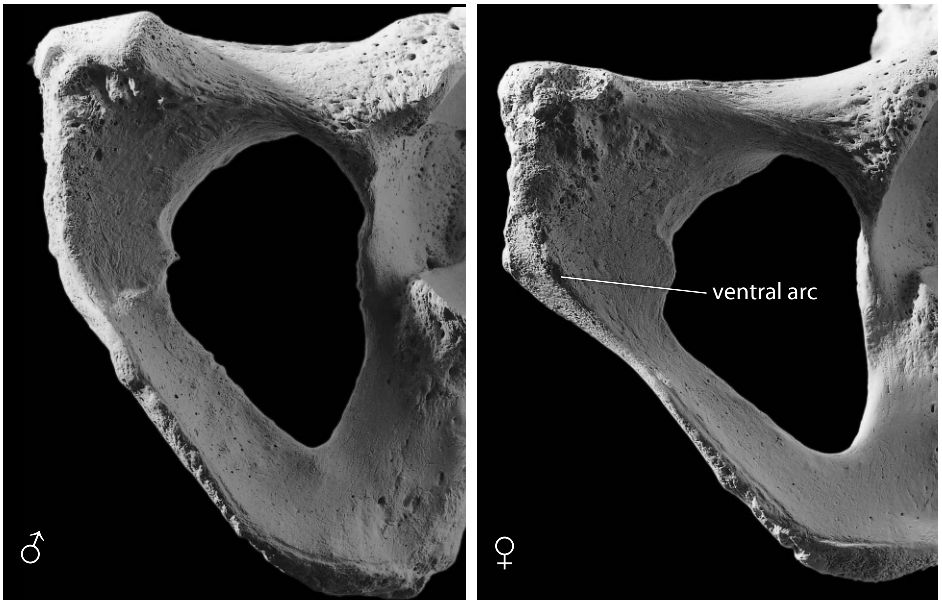
The Phenice method should only be used for fully adult material. Accuracy of sexing based on this method ranges from 96% to 100%, the highest ever achieved in the skeleton, but Lovell (1989) has suggested that accuracy might be reduced in the case of older adult specimens. In 1990, MacLaughlin and Bruce tested the Phenice characters for accuracy of sex identification on skeletal series from London, Leiden, and Scotland. They were unable to confirm the accuracy obtained by Phenice and others, achieving success on only 83% of the English, 68% of the Dutch, and 59% of the Scottish. They found the subpubic concavity to be the single most reliable indicator. Using 1,284 pubic bones from the Los Angeles County Coroner's collection, Sutherland and Suchey (1991) reported that they achieved 96% sexing accuracy using the ventral arc alone. They note that this feature first appears at age 14 but does not become marked until age 20. The discrepancy between these two major tests of the Phenice technique remains unexplained, but Ubelaker and Volk (2002) note that experience plays a role in conditioning results from the use of this technique. The best advice for sexing of the os coxae, as for aging the skeleton, is to use all of the available data.

18.5 Estimation of Stature

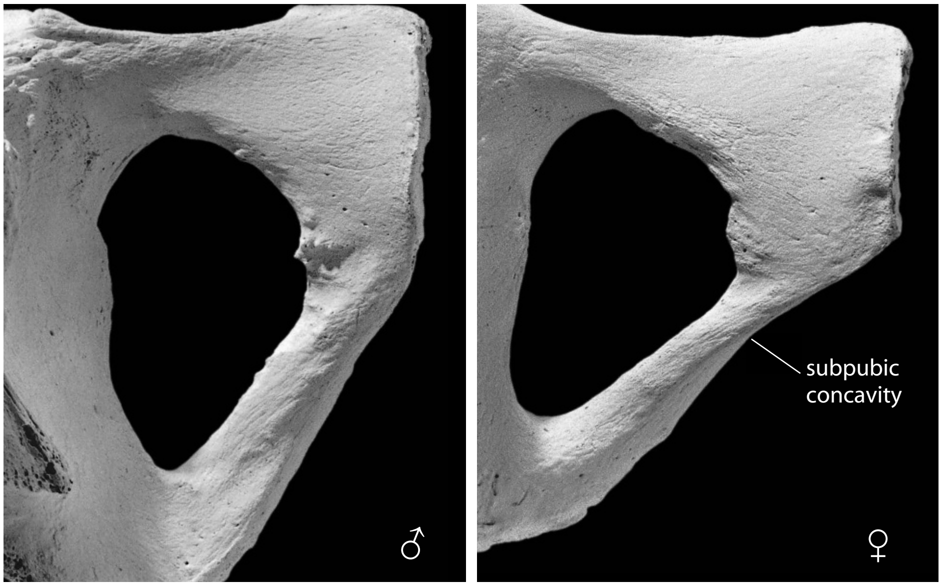
Estimating individual stature from bone lengths has a long history in physical anthropology. The fact that the height (stature) of the human body correlates with limb bone length across all ages allows the osteologist to reconstruct an individual's stature from different skeletal elements. Unfortunately, the correlation is imperfect within living populations and varies between populations. Based on studies of skeletons from individuals of known stature, several investigators have derived regression equations useful in estimating stature in different human populations.

To estimate stature, based on the maximum length of a male femur from a Mesoamerican ar-

Figure 18.27 *(Opposite)* **The Phenice (1969) technique for sexing the pubic portion of the os coxae.** Left ossa coxae shown. In each comparison, the male is on the left and the female is on the right. These ossa coxae are the ones illustrated in Figure 18.26. Approximately two-thirds natural size.



Ventral arc. Orient the pubis so that its rough ventral surface faces you and you are looking down along the plane of the pubic symphyseal surface. The ventral arc is a slightly elevated ridge of bone that sweeps inferiorly and laterally across the ventral surface of the pubis, merging with the medial border of the ischiopubic ramus. Thus, the ventral arc, when present, sets off the inferomedial corner of the pubic bone in ventral view. It is present only in females. Male ossa coxae may have elevated ridges in this area, but these do not take the wide, evenly arching path of the female's ventral arc, nor do they set off the lower medial quadrant of the pubis.



Subpubic concavity. Turn the pubis over, orienting it so that its smooth, convex dorsal surface faces you and you are once again sighting along the midline. Observe the medial edge of the ischiopubic ramus in this view. Female ossa coxae display a subpubic concavity here; the edge of the ramus is concave in this view. However, males show no evidence of a concavity here. Male edges are straight or very slightly concave.

Medial aspect of the ischiopubic ramus. Turn the pubis 90°, orienting the symphyseal surface so that you are looking directly at it. Observe the ischiopubic ramus in the region immediately inferior to the symphysis. The medial aspect of the ischiopubic ramus displays a sharp edge in females. In males this surface is fairly flat, broad, and blunt.

chaeological site, for example, the osteologist would apply the formula derived by Genovés from modern Mexican samples and published in 1967. This formula is as follows:

$$\textit{stature}\,(\text{cm}) \pm 3.417 = 2.26 \times \textit{femur length} + 66.379$$

If femur length is known, stature may be calculated with about a 68% probability that the calculated value falls within 3.417 cm of the actual stature of the individual. This formula, of course, can be validly applied only to Mexican samples, but Bass (2005) and Bennett (1993) provide useful tables for stature estimation in different human groups. Most of these formulae are based on the lengths of one or more bones.

Trotter and Gleser (1958) developed formulae for estimating stature based on the Korean War dead, extending their earlier work on World War II remains in an anatomical collection. Formulae were presented for "racial" groups. The Genovés (1967), Trotter and Gleser (1958), and Trotter (1970) formulae for stature estimation are the most frequently used methods in North America. Table 18.5 is taken from the latter publication. As Feldesman and Fountain (1996) note, if the specimen's ancestry (race) is unknown, it is best to use generic equations of stature. Formicola (1993) evaluated various stature formulae on 66 archaeological skeletons from seven European countries. They found that the Trotter and Gleser formulae for African-Americans worked better than those for European-Americans.

There has been some discussion on how to accommodate old data sets to the modern forensic world (Jantz, 1992, 1993; Giles, 1993). As Jantz (1992) notes, the most commonly used female stature formulae were derived from the Terry Collection, skeletons from people who died in the early 1900s. To what extent should formulae based on those samples be modified to reflect the secular changes in bone length and body height undergone during the last century? Giles (1991)

Table 18.5 **Equations used to estimate stature (in cm) from long bone lengths[a] of individuals aged 18 – 30[b]**

European-American Males						**African-American Males**					
3.08	×	Hum	+	70.45	± 4.05	3.26	×	Hum	+	62.10	± 4.43
3.78	×	Rad	+	79.01	± 4.32	3.42	×	Rad	+	81.56	± 4.30
3.70	×	Uln	+	74.05	± 4.32	3.26	×	Uln	+	79.29	± 4.42
2.38	×	Fem	+	61.41	± 3.27	2.11	×	Fem	+	70.35	± 3.94
2.68	×	Fib	+	71.78	± 3.29	2.19	×	Fib	+	85.65	± 4.08
European-American Females						**African-American Females**					
3.36	×	Hum	+	57.97	± 4.45	3.08	×	Hum	+	64.67	± 4.25
4.74	×	Rad	+	54.93	± 4.24	2.75	×	Rad	+	94.51	± 5.05
4.27	×	Uln	+	57.76	± 4.30	3.31	×	Uln	+	75.38	± 4.83
2.47	×	Fem	+	54.10	± 3.72	2.28	×	Fem	+	59.76	± 3.41
2.93	×	Fib	+	59.61	± 3.57	2.49	×	Fib	+	70.90	± 3.80
East Asian Males						**Mexican Males**					
2.68	×	Hum	+	83.19	± 4.25	2.92	×	Hum	+	73.94	± 4.24
3.54	×	Rad	+	82.0	± 4.60	3.55	×	Rad	+	80.71	± 4.04
3.48	×	Uln	+	77.45	± 4.66	3.56	×	Uln	+	74.56	± 4.05
2.15	×	Fem	+	72.57	± 3.80	2.44	×	Fem	+	58.67	± 2.99
2.40	×	Fib	+	80.56	± 3.24	2.50	×	Fib	+	75.44	± 3.52

[a] All lengths used are maximum lengths

[b] To estimate stature of older individuals, subtract 0.06 (age in years, 30) cm; to estimate cadaveric stature, add 2.5 cm. From Trotter (1970). The tibia is not included; see text for rationale.

makes further comments regarding stature loss in the elderly. Jantz and colleagues (1995) also note that the Trotter and Gleser stature formulae involving tibial length produce stature estimates averaging 2–3 cm too great when used with properly measured tibiae. They show that the original formulae involving tibiae are based on mismeasured tibiae (the malleolus was omitted in maximum length measurements). Finally, Owsley (1995) notes that stature can be defined in several ways, ranging from forensic (*e.g.,* from a driver's license) to biological (from cadavers or living individuals). He suggests that biological stature estimations based on long bone lengths are generally less precise than many have assumed. Table 18.6 is from Owsley (1995).

18.6 Estimation of Ancestry

Imagine a sample of 1,000 people—a sample composed of 400 native Nigerians, 300 native Chinese, and 300 native Norwegians. If these people seated themselves randomly at a lecture, the speaker would be able to tell, simply by looking at their faces, whether their ancestry was Asian, African, or European. The sorting accomplished on the basis of soft tissue facial features would correspond perfectly to the geographic origin of the three major components of the sample.

This kind of sorting within the species *Homo sapiens* is usually termed racial sorting. However, there are no "pure" human races (A.A.P.A., 1996). By definition, all members of the same species

Table 18.6 **Regression equations for estimating forensic stature from skeletal remains**[a]

	Factor	Measurement(s) in mm	Constant	90% PI	N
European-American Males	0.05566	Femur Max L + Tibia L	21.64	± 2.5"	62
	0.05552	Femur Max L + Fibula L	22.00	± 2.6"	54
	0.10560	Femur Max L	19.39	± 2.8"	69
	0.10140	Tibia L	30.38	± 2.8"	67
	0.15890	Ulna L	26.91	± 3.1"	62
	0.12740	Humerus L	26.79	± 3.3"	66
	0.16398	Radius L	28.35	± 3.3"	59
European-American Females	0.06524	Femur Max L + Tibia L	12.94	± 2.3"	38
	0.06163	Femur Max L + Fibula L	15.43	± 2.4"	42
	0.11869	Femur Max L	12.43	± 2.4"	48
	0.11168	Tibia L	24.65	± 3.0"	43
	0.11827	Humerus L	28.30	± 3.1"	45
	0.13353	Ulna L	31.99	± 3.1"	40
	0.18467	Radius L	22.42	± 3.4"	38
African-American Females	0.11640	Femur Max L	11.98	± 2.4"	18
African-American Males	0.16997	Ulna L	21.20	± 3.3"	14
	0.10521	Tibia L	26.26	± 3.8"	19
	0.08388	Femur Max L	28.57	± 4.0"	17
	0.07824	Humerus L	43.19	± 4.4"	20

[a] Note that the bone measurements should be in millimeters, but that all constants were converted to predict statures and prediction intervals in inches because most North American forensic applications record stature in inches. For example, if the maximum length of the femur from a probable white male is 454mm, the forensic stature is estimated by: 0.10560 (454) + 19.39 = 67.33±2.8 inches. This person, if a white male, would have a roughly 90% chance of having a forensic stature between 64.5 and 70.1 inches (5 feet 4½ inches to 5 feet 10 inches).

have the potential to interbreed, and hence any subspecific classification is arbitrary. Defining the term "race" has proven difficult in the history of physical anthropology because concepts of race have often been based on composites of biological, social, and ethnic criteria used in a typological fashion. The confusion arising from these difficulties has persuaded some anthropologists to conclude that the very use of the term "race" is counter-productive. In osteological work, particularly work in forensic contexts, the determination of race, or geographic ancestry, is usually an important consideration.

The title of a paper by physical anthropologist Kenneth Kennedy (1995) asked, "But Professor, Why Teach Race Identification if Races Don't Exist?" Typological race concepts in physical anthropology have gone the way of the dinosaurs, but human populations are routinely divided into separate "races" (African-Americans, European-Americans, Native Americans, and Hispanics) in governmentally mandated programs, the popular media, and the forensic sciences. As St. Hoyme and İşcan (1989) note, human osteologists who examine human bones must communicate with law-enforcement personnel, students, and the general public. How people are categorized by others depends on law and custom. The United States government's bureaucratic approach to "race" is quite specific in this regard, noting that its classifications (American Indian or Alaskan native; Asian or Pacific Islander; Black; Hispanic; White; or other) "should not be interpreted as being scientific or anthropological in nature" (O.M.B., 1997).

Most forensic applications bring the human osteologist into contact with medical examiners, law enforcement, or other government personnel who expect missing and/or found persons to be classified in terms of their bureaucratic "races" as defined by the government. These "racial" categories, of course, mix historical and social phenomena with biology. Gill (1995) provides an example of this by pointing out that in the United States, a person who is of 75% European descent, but has a black African grandparent is considered African-American rather than European-American. Today, it is common for parents of completely different geographic ancestry to have children whose anatomical configurations will defy assessment of ancestry. How does the osteologist deal with these social and biological realities?

The osteologist's role, particularly in the forensic setting, is often to individualize an unknown's osteological remains by assessing the sex, age, stature, and ancestry of the individual. The ability to determine the geographic ancestry of a skeletal unknown is useful for narrowing the possibilities and leading to a positive identification in many cases. Yet as a biological scientist, the human osteologist knows that all variation is continuous, not discrete. As Kennedy (1995) notes, there is a paradox in the scientific rejection of "race" and its survival in medico-legal contexts. As Kennedy says (1995: 798), "Forensic anthropologists are keenly aware that neither the medical examiner, the judge, the attorney client nor the sheriff would appreciate a lecture on the history of the race concept in Western thought. These professionals want to learn if the skeleton on our laboratory table is a person of Black, White, Asian or Native American ancestry." To conduct analysis of ancestral background, the osteologist may use osteological traits known to vary among different human populations in different parts of the world.

As Brace (1995: 172) explains, "Skeletal analysis provides no direct evidence for skin color for example, but it does allow an accurate estimate of original geographical origins. African, eastern Asian, and European ancestry can be specified with a high degree of accuracy. Africa of course entails 'black,' but 'black' does not entail African." Marks (1996) notes that the tendency for Americans to classify people into one of three "races" is an artifact of history and statistics—immigrants to North America have come mostly from ports where seafaring vessels in earlier centuries could pick them up. Hence, the American notion of "black" is actually west African, and the notion of "Asian" is actually east Asian. People from south Asia (India and Pakistan—people with darker skins and facial resemblances to Europeans) immigrated in smaller numbers and therefore did not merit as much bureaucratic concern.

A real example of the dilemma facing human osteologists in the area of "racial" identification comes from the work of Katz and Suchey (1989) on their sample of Los Angeles male pubic symphyses. These workers, in a paper entitled "Race Differences in Pubic Symphyseal Aging Patterns in the Male," assess the Los Angeles County Coroner sample used to generate the Suchey-

Brooks system of symphyseal aging (Section 18.3.6). They segregated the symphyses into "racial" categories. They did not use the California death certificates made out by coroner investigators. As Katz and Suchey note, these examiners used nonuniform mixtures of biological, cultural, and linguistic variables in their determinations. Rather, Suchey divided the autopsied individuals into 486 Whites, 140 Blacks, and 78 Mexicans and noted that her Mexican category is a category showing Mexican ancestry coupled with a strong American Indian racial component. Katz and Suchey found that pubic symphyseal metamorphosis was accelerated in Blacks and Mexicans, but they could not address the issue of causality.

When DNA can be extracted from a subject's osteological remains, accurate determination of the ancestral population and even familial relationships becomes possible. DNA typing of skeletal remains has the potential to provide the best available information regarding the populational affinity of the individual. Mitochondrial DNA (mtDNA) is a small portion of the human genome that is inherited only from the mother. Mitochondrial DNA evolves about 10 times faster than nuclear DNA, making mtDNA a useful tool for discriminating between even closely related populations (Wallace and Torroni, 2009). See Chapter 22 for more information on molecular techniques in osteology.

Whereas molecular and soft tissue characteristics such as skin color, hair form, and facial features often allow unambiguous attribution of geographic ancestry among living people, the hard tissues display less-reliable signatures of ancestry. There are, in fact, no human skeletal markers that correspond perfectly to geographic origin. The problems in using discrete cranial and dental

Table 18.7 Useful cranial traits for determining ancestry

	Native Americans	European-Americans	African-Americans
Incisors	shovel-shaped	blade-form	blade-form
Zygomatics	robust, flaring	small, retreating	
Prognathism	moderate	very limited	marked alveolar and facial
Palate	elliptic	parabolic	hyperbolic
Cranial sutures	complex	simple	simple
Nasal spine	medium, "tilted"	long, large	small
Chin	blunt, median	square, bilateral, projecting	blunt, median, retreating
Ascending ramus	wide, vertical		narrow, oblique
Palatine suture	straight	jagged	arched
Zygomatic tubercle	present		
Incisor rotation	present		
Nasal profile	concavo-convex	straight	
Sagittal arch	low, sloping		
Wormian bones	present		
Nasals	low, tented	highly arched, steeplelike	low, flat
Nasal aperture	medium		wide
Zygomaticomaxillary suture	angled	curved	curved
Dentition		small, crowded	large molars
Nasal sill		very sharp	very dull or absent
Nasion		depressed	
Cranial vault		high	low
Mandible		cupping below incisors	
Inion hook		present	
Postbregmatic depression		present	

From Rhine (1990) and Gill (1995).

features to determine ancestry are perhaps best appreciated by considering what most osteologists agree is a racial marker: the shovel-shaped incisors seen in high frequency in modern Asian populations. A review and compilation of data on incisor shoveling by Mizoguchi (1985) show wide ranges of expressivity and incidence values in different extant human groups. Suffice it to say that incisors from Asian populations show a high incidence of shoveling, but also that the presence of shoveled incisors is hardly grounds for confident identification of a dentition as Asian.

The skull is the only part of the skeleton that is widely used in estimating geographic ancestry [but see İşcan and Cotton (1985) for a consideration of the pelvis as a racial indicator and Baker et al. (1990), Trudell (1999), and Gill (2001) for femoral techniques. Holliday et al. (1999) provide a discriminant function for multiple elements]. Even with this element, all workers agree that racial estimations are usually more difficult, less precise, and less reliable than estimations of sex, age, or stature. Despite decades of research, much more osteological work on geographic differentiation within *Homo sapiens* remains to be done and is urgently needed. Work on modern skulls of known origin has revealed certain tendencies.

Howells (1995) notes that the human species lacks well-defined subspecies but has clear local tendencies of variation. It is simply not possible to attribute every human cranium to one or another geographically defined group on the basis of its morphology or measurements—populations of the human species are morphologically too continuous for this. Howells conducted exhaustive and long-term studies on a selected sample of 2,504 human crania from around the world. He used 57 measurements on each skull and employed multivariate statistical techniques with a computer to show clearly that human variation in cranial shape, as represented by his measurements, is patterned and that "target" skulls of unknown ancestry could often be unambiguously placed in a parent "population."

Compared to populations of African or European origin, Asian populations display skulls characterized by narrow, concave nasal bones, prominent cheek bones, circular orbits, and shoveled incisors. Compared to Asians and Europeans, African crania have been characterized as showing wide interorbital distances, rectangular orbits, broad nasal apertures with poor inferior definition, gracile cranial superstructures, and pronounced total facial and alveolar prognathism. European crania have been characterized as displaying narrow nasal apertures with sharp inferior borders (sills), prominent nasal spines, heavy glabellar and supraorbital regions, receding cheek bones, and large, prominent nasal bones.

Given the limitations of using such subjective criteria for recognizing geographical ancestry, some have turned to cranial metric methods for the assessment of racial status (Giles and Elliot, 1962; Howells, 1969b). One such attempt is that of Gill (1984, 1998), which addresses the problem of sorting European from Native American crania.

Gill (1995) provides a compendium of traits useful in assessing ancestry in an American context in his article "Challenge on the Frontier: Discerning American Indians from Whites Osteologically." He notes that the Giles-Elliot discriminant function approach has been shown to be ineffective at sorting crania, particularly in the Northwestern Plains area where he works in both forensic and archaeological contexts. Gill considers races to be statistical abstractions of trait complexes, not pure entities or rigidly definable types. Table 18.7 is a list of useful traits of the teeth and cranium taken from his paper. See Tyrrell (2000) for another consideration and Edgar (2005) for a consideration of prediction of ancestry from dental anatomy.

The attention now being given to the origin of anatomically modern *Homo sapiens* in the later Pleistocene (Mellars and Stringer, 1989; White et al., 2003) should stimulate more work on skeletal differentiation within geographically separated populations of the species. Meanwhile, all of the techniques noted here, both visual and metric, should be applied only on adult remains and with comparative material. See Krogman and İşcan (1986), İşcan (1988), and Gill (1998) for further discussions on this topic.

18.7 Identifying the Individual

In paleontological and prehistoric archaeological contexts, fossils are sometimes given nicknames like 'Dear Boy' or 'Lucy,' but we will never know how members of their own species identified them. In historic archaeological contexts, it is possible that skeletal remains may be identified as unique individuals, such as named Egyptian pharaohs or people buried beneath headstones in historic cemeteries. In the forensic realm, the human osteologist is often presented with unidentified skeletal remains. The positive identification of human skeletal remains — the unequivocal matching of teeth, crania, or postcranial remains with unique, named individuals — is often the most important step in the analysis. The identification of sex, age, stature, and ancestry all narrow the windows of possible identification — possible matching — to known individuals (often missing or unaccounted for). The last step in the process of identification sometimes involves matching unique features of the "unknown" skeleton with unique characters of the "known" missing.

DNA analysis is the best method for testing hypotheses about the identity of skeletal remains. The general approach is to compare DNA from the skeleton with the DNA of the presumed relatives. For a number of variable regions of the DNA, the odds of a match between unrelated individuals are extremely low. Exactly how low is a matter of debate for cases involving blood samples from living individuals (Devlin et al., 1994), but in osteological contexts this is rarely, if ever, a concern. DNA typing has been used to identify skeletonized individuals in contexts involving mass deaths (the Branch Davidian incident in Waco, Texas: Houck et al., 1996), mass graves (Guatemala and former Yugoslavia: Boles et al., 1995; Primorac et al., 1996), remains of military personnel (Vietnam: Holland et al., 1993), war criminals (Josef Mengele: Jeffreys et al., 1992), and numerous forensic cases involving murder victims (*e.g.*, Hagelberg et al., 1991; Sweet and Sweet, 1995). Even though the determination of familial relationships is most applicable in forensic or historical contexts, archaeological analysis of mortuary rituals and burial practices can often be advanced if the general relationships of the interred individuals can be established (Stone and Stoneking, 1993). Establishing the familial relationships between individuals in the same prehistoric population requires more detailed analysis than is usually attempted.

Fingerprint analysis, of course, is a means by which forensic specialists routinely match criminals with their crimes. As the soft tissue features of the body decay or are incinerated, however, the use of fingerprints, hair, and personal items to individuate the deceased becomes impossible. Teeth, the skeletal structures most resistant to such destruction, are often used to identify people in mass disasters. Such individuation via teeth and their modifications, usually by dentists, has traditionally been accomplished by **forensic odontologists**, specially trained experts accomplished at such identifications. Radiographs and other dental records kept by dentists are matched against modifications on the deceased's teeth, often resulting in a positive identification (Kogon and MacLean, 1996).

Another means of establishing a positive identification on unknown skeletal remains is the comparison of those remains with medical radiographs taken when the individual was alive. Fractures, of course, can heal, but there are often trabecular and cortical points of identity through which a positive identification can be established. Postcranial skeletal characters (Owsley and Mann, 1992; Kahana et al., 1998) and frontal sinus morphology (Ubelaker, 1984; Kirk et al., 2002; Smith et al., 2002; Christensen, 2004) have been shown to be individually specific. The success of radiographic identification of unknown human remains, like that of many other techniques in human osteology, depends on the experience of the interpreter. Hogge et al. (1994) showed that the most-accurate identifications came from cranial remains and the cervical spine and chest, whereas the least-accurate identifications were made on the lower leg.

More recently, techniques that superimpose the skull of an unknown deceased individual on old photographs, motion pictures, or videotapes have been developed (İşcan and Helmer, 1993). Austin-Smith and Maples (1994) have tested the reliability of such superimposition methods and provide a good review of the techniques, limitations, and successes. When the anterior teeth are recovered with the skull and a smiling photograph with the teeth in focus is available, the shapes

of individual teeth and their relative positions are often distinctive enough for an identification to be made. Using only one photograph, Austin-Smith and Maples found a 9% chance of false identification, but when two photographs representing a difference of about 90° in the angle of the face to the camera were used for superimposition, the chance of false identification dropped to less than 1%.

A final means of personal identification based on skeletal remains involves forensic three-dimensional facial reconstruction. A series of techniques exists for the "restoration" of the soft tissue cover of a human skull (İşcan and Helmer, 1993; Neave, 2000). A recent review of the history of development and current status of such techniques by Tyrrell and colleagues (1997) notes that facial reconstruction still stands on the threshold between art and science. These authors conclude that current methods are useful, but insufficiently reliable to serve as evidence of positive identification in a court of law. Clement and Ranson (1998) provide a broad overview of craniofacial identification in forensic work and DeGreef and Willems (2005) review progress and prospects in this field.

Suggested Further Readings

Adams, B. J., and Byrd, J. E. (Eds.) (2008) *Recovery, analysis, and identification of commingled human remains.* Totowa, NJ: Humana Press. 374 pp.

> This comprehensive, edited volume highlights case studies that illustrate individual identification, minimum number of individuals, and other commingling issues at mass-fatality sites using osteometric, radiological, and molecular methodologies.

Baccino, W., Ubelaker, D. H., Hayek, L. A. C., and Zerilli, A. (1999) Evaluation of seven methods of estimating age at death from mature human skeletal remains. *Journal of Forensic Sciences* 44: 931–936.

> This paper reviews and evaluates common age estimation methods using 19 French autopsy individuals of known age at death.

Bennett, K. A. (1993) *A field identification guide for human skeletal identification* (2nd ed.). Springfield, IL: C. C. Thomas. 113 pp.

> A compilation of tables of data useful in estimating sex, age, stature, and ancestry.

Caldwell, P. C. (1986) New questions (and some answers) on the facial reproduction techniques. In: K. J. Reichs (Ed.) *Forensic osteology: Advances in the identification of human remains.* Pp. 229–255. Springfield, IL: C. C. Thomas.

> Discussion of the art and science of facial reproduction.

Gill, G. W., and Rhine S. (Eds.) (1990) *Skeletal attribution of race: Methods for forensic anthropology.* (Anthropological Paper No. 4). Albuquerque, NM: Maxwell Museum of Anthropology. 99 pp.

> An edited volume with a variety of articles about identifying ancestry.

Hamilton, M. E. (1982) Sexual dimorphism in skeletal samples. In: R. L. Hall (Ed.) *Sexual dimorphism in* Homo sapiens. Pp. 107–163. New York, NY: Praeger.

> A review of the problems and prospects for the use of skeletal material in estimating sexual dimorphism.

İşcan, M. Y. (1988) Rise of forensic anthropology. *Yearbook of Physical Anthropology* 31:203–230.

> This review article traces the development of forensic anthropology and provides a wealth of citations.

İşcan, M. Y. (Ed.) (1989) *Age markers in the human skeleton.* Springfield, IL: C. C. Thomas. 359 pp.

This edited volume provides a variety of perspectives on the determination of age, from fetal life through adulthood, from various parts of the human skeleton and teeth. Its chapters, written by primary workers in the field of skeletal biology, summarize the limitations, advantages, and current status of various techniques used to determine skeletal age.

İşcan, M. Y., and Helmer, R. P. (Eds.) (1993) *Forensic analysis of the skull.* New York, NY: Wiley-Liss. 276 pp.

An edited volume with a variety of chapters covering aging, sexing and racing the skull, and principles and techniques of facial reconstruction.

İşcan, M. Y., and Kennedy, K. A. (Eds.) (1989) *Reconstruction of life from the skeleton.* New York, NY: Alan R. Liss. 315 pp.

This edited volume is a valuable sourcebook on a wide range of issues, including the assessment of sex, age, stature, and ancestry.

Krogman, W. M., and İşcan, M. Y. (1986) *The human skeleton in forensic medicine* (2nd ed.). Springfield, IL: C. C. Thomas. 551 pp.

This updated classic is an essential, comprehensive guide to making the estimations discussed above, particularly in forensic contexts.

Lovejoy, C. O., and colleagues. (1985) Eight papers on Todd and Libben skeletal material. *American Journal of Physical Anthropology* 68:1–106.

This collection of research papers illustrates work in both archaeological and forensic contexts.

Scheuer, L. and Black, S. (2000) *Developmental juvenile osteology.* San Diego, CA: Academic Press. 587 pp.

A comprehensive reference that is a must-have when doing any analysis of immature osteological material.

Ubelaker, D. H. (1987) Estimating age at death from immature human skeletons: An overview. *Journal of Forensic Sciences* 32:1254–1263.

A comprehensive review of the methods and limitations of age estimation for immature skeletal remains.

Ubelaker, D. H. (1999) *Human skeletal remains: Excavation, analysis, interpretation* (3rd ed.). Washington, DC: Taraxacum. 172 pp.

A concise guide to identification of the variables covered here, including valuable tables and charts.